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Wright-Patterson Air Force Base, Ohio

A COMPARATIVE ANALYSIS OF THE
D041 SINGLE MOVING AVERAGE AND
OTHER TIME SERIES ANALYSIS
FORECASTING TECHNIQUES

Jim S. Brantley, Captain, USAF
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This thesis examines the forecasting technique used in the Air Force Logistics Command D041 reparable asset management system. The process of retrieving usable data from the D041 Data Bank is described in some detail, including computer problems and potential pitfalls. It was hypothesized that the mean of the absolute values of the D041 forecast error was equal to zero. This hypothesis could not be rejected, but the results are questionable because "after the fact" forecasts were used. It was further hypothesized that another time series forecasting technique (exponential smoothing) would also yield an error distribution with a mean of zero. This hypothesis could not be rejected; however, the variances for the exponential smoothing forecast error distributions were less than the D041 forecast error distributions for all four lead times examined (one, two, three and four quarters).

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A COMPARATIVE ANALYSIS OF THE D041 SINGLE MOVING AVERAGE AND OTHER TIME SERIES ANALYSIS FORECASTING TECHNIQUES

A Thesis

Presented to the Faculty of the School of Systems and Logistics

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Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

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CHAPTER I

INTRODUCTION

Background

During the past fifteen years, much outside pressure--Congressional and taxpayer--has been placed on the Department of Defense to improve the management of its materiel acquisition system as well as other resource expenditure programs. This pressure, combined with the aggressiveness of individuals involved in the materiel systems, has generated many innovative techniques to improve the support of our weapons systems (1:22-23). As a result, the focus has been on obtaining the maximum national defense for minimum dollar expenditure; a goal to be achieved through the effective use of national resources.

The management of the Air Force portion of these national responses is the responsibility of the Air Force Logistics Command (AFLC), which ". . . must maintain the ability to replenish base stock levels through a constant flow of recoverable materiel to and from our global deployed Air Force units [12:2-2]." The materiel support system required to accomplish this mission involves the management of 1.8 million line items worth approximately 9 billion dollars (7:34).

Statement of the Problem

Forecasting for and acquiring spare parts is an important facet of the materiel support system. Forecasts are used to develop dependable systems and to formulate decisions concerning the technical and economic feasibility of retaining a system in use (4:15-16). The economics of spiraling prices and austere budgets make reliable estimates, or forecasts, especially critical. The exponential acceleration of spares cost provides sufficient justification for basing requirements computations upon the best available forecasting methodology (1:22). As new data sources become available, as improvements are made in forecasting techniques, as added insight of needs is received, and as other uses for planning factors are considered, current forecasting methods require modification or complete change. Forecasting is an evolutionary, dynamic process, and the method which served well yesterday may not continue to be the best method for use today (8:351-358). Operating systems managers in Headquarters AFLC suspect that the forecasting technique incorporated in the AFLC materiel support system is biased, i.e., the expected value of the forecast error is not zero. The problems analyzed in this research are to determine the bias of the current AFLC forecasting technique and to compare this bias to that of other selected forecasting methods.

AFLC Forecasting System

The Air Force Logistics Command manages spares according to the provisions of the Recoverable Consumption Item Requirements System (D041), a computer based inventory control system (12:1-1). In this context, spares are defined as recoverable items coded with an Expendability-Recoverability-Reparability-Code (ERRC) of XD, which indicates that the spare is reparable at the base or depot level when necessary. Spares constantly move through a cycle of transactions from the supply activity's warehouse, to installation on an end item, to removal from a higher assembly after failure, through a repair facility, and then back to the supply activity ready for reissue once again. Spares stockage, after initial procurement with the weapon system, is based primarily on past demands or reparable generations. Information concerning these reparable generations at both base and depot level is accumulated and consolidated through the Air Force Recoverable Asset Management System. This data is input to the D041 System to provide the data base which is used to produce the forecasts. These forecast computations are made monthly, for quarterly periods. The initial quarter identifies specific items requiring buy, repair, termination and disposal actions (12:1-1). The second quarterly computation (FY-2) is used for adjusting previously initiated item actions, updating workload projections for annual negotiation, buy

actions in process, termination and disposal (12:1-1). The third quarterly computation (FY-3) is used to develop budget requests and update logistic actions in process (12:1-2). The fourth quarterly computation (FY-4) is used to update logistics actions in process, initiate new actions, and provide data input into other systems (12: 1-2).

Forecasts are made in the form of a reparable generation rate, which provides a basis for the requirements computation performed by the item managers. The computations combine the forecast with other asset availability data to determine actual requirements. These requirements are further modified by subjective external factors called additives (5).

The intricacy and subjectivity of the requirements computation procedures are beyond the scope of the proposed research effort. This research focused only upon the statistical model incorporated in the D041 System used to forecast reparable generations. Consequently, the only variables considered were the data points, or actual reparable generations and the resulting forecasts.

Research Justification

A number of sophisticated statistical forecasting techniques are available, but time series analysis seems to be the most promising for forecasting demand data. Time

series analysis is based upon the concept that a sequence of observations composing a time series is one realization of jointly distributed random variables. The past history of the time series is thus used to provide information about the mechanism which describes its evolution through time, and the mechanism derived is used to forecast the future (1:18-19).

The procedural forecasting instructions outlined in current Air Force directives are descriptive translations of the basic mathematical forecasting models used to predict future requirements. Little management attention is given to the forecasting technique unless significant disparities exist between forecasts and reparable generations. The tendency, even then, is to modify the forecasts rather than to question the validity of the technique generating the forecasts (6). The effectiveness of the AFLC spares support system depends upon the accuracy of forecasts; therefore, it is imperative that the most accurate forecasting techniques available be used. The system currently in use (D041) depends primarily on one of the simplest statistical techniques available--the weighted moving average, specifically a twenty-four month moving average (12). Its effectiveness must be determined and compared to that of other forecasting techniques if the Air Force is to operate an efficient logistics system.

The moving average technique smooths fluctuations in time series and is applied to trend lines as well as seasonal and cyclical variations. Smoothing takes place by fitting a straight line to successive groups of n years by the method of least squares (13:337). However, when n is 24 months, a straight line may not adequately fit. A parabola may perhaps be the best fit in the least-squares sense (13:861). The moving average technique also assumes that successive observations are statistically independent, i.e., assuming this year's reparable generations are independent of last year's generations, but usually this is not true (13:865). This technique assumes that the data are stationary (data mean and variance do not change over time) and that the data are not autocorrelated (independent of previous time periods). The moving average technique is simple, and easy to use because of its straightforward calculations. In formula form, the predicted value of reparable generations, $\hat{g}$, for period t (made in period t-1) is g_{t-1} such that the average for time t+1 is:

$$\hat{g}_{t+1} = g_{t-1} + \frac{1}{n}(g_t - g_{t-n}) \qquad \text{(Equation 1)}$$

where:

$\hat{g}_{t+1}$ is the forecast reparable generations for period t+1,

n is the number of periods,

t is the time period,

g_t is the actual reparable generation in period t, and

g_{t-n} is the actual reparable generations in period $t-n$.

The error associated with this forecast is the difference between the forecast value and the actual demand value. With the simple moving average forecasting technique the forecast error is small, but its standard deviation is greater than the standard deviation of the actual data (11:4). The moving average technique merely smoothes out the fluctuations in the data by "moving" the arithmetic mean value through the time series (10:234). This technique reacts slowly to sudden changes in the data and is ineffective if the data is erratic. If a step change in demand occurs, the moving average takes n periods (the moving average base) to level off at the new demand (11:5). However, in the case of continuously increasing demand, estimated demand responds slowly and always underestimates actual demand. When this occurs, the forecast becomes more biased (11:4); that is, the absolute value of the expected value of the error increases. The forecast lags behind the trend in demand, and the amount of lag depends on the number of periods in the forecast. Alterations are then required to offset the bias in the moving

average forecast causing yet another problem. The "corrected" level often overshoots the actual demand and does not return to the mean. The moving average technique is not easily adapted to adjust for forecasting over long periods, nor does it allow for averaging over arbitrarily varying time periods (11:6).

Application of the moving average technique to time series data requires data with a characteristically linear function and a definite rhythmic pattern of fluctuation which repeats periodically (10:234).

In summary, the moving average is simple to compute and has merit if the basic assumptions have been met, but it has a serious disadvantage in that it responds slowly to changes in the demand pattern (11:6). Data at the beginning of a series are lost. Moving averages may generate cycles or other movements which are not present in the original data. Moving averages are affected by extreme values (11:6). A method of averaging that allows for an easy change of the series length and overcomes the effects of extreme values should be used. Further support for discontinuing the use of the simple moving average was found in the Predictive Techniques Study, Phase I: "Comparison of Some Forecast Methods" done by M. D. Lum, L. L. Blair and J. R. Stuart. They used generated data and concluded that the 24 month single item moving average for items with long-term exponential or linear trend was the worst of all

methods tested, and that double exponential smoothing with specified constants using Brown's tracking signal (an out-of-control signal that indicated the difference between the forecast and new datum has become significantly larger than one would expect by chance) ranked best for the items with exponential trends. The study also recommended that efforts be made to investigate applications of other techniques, and that real data be used in the future studies. A more reliable method for forecasting appears to be necessary and a search for this method has led statisticians to the exponential smoothing technique (9:iii-v).

Exponential smoothing uses the fundamental idea that any new estimate of demand is related to the previous estimate corrected for new information. Like the simple moving average, exponential smoothing also assumes stationarity and independence. The estimating equation is:

$$\text{New Estimate} = \Theta(\text{New Demand}) + (1-\Theta)(\text{Old Estimate}) \quad \text{(Equation 2)}$$

where $0 < \Theta < 1$ is the smoothing constant. Small values of the smoothing constant (Θ) can be used to place heavier emphasis on demands from the distant past and little weight on more recent demands. Conversely, larger values of theta can be used so that the distant past has little effect on the forecast (11:7). By varying theta, the item's demand history can be increased or decreased in importance

for making forecasts, and the method can be repeated using as many different thetas as desired. Overall, when the smoothing constant is small, the function behaves like the average of a large amount of past data, and therefore the variance of the estimate is small. When the smoothing constant is large the function will respond rapidly to changes in the pattern. The advantages of exponential smoothing are simplicity, ease of calculations, minimal data requirements once the forecasting method has been developed, simple control procedures for the forecasts; and the straightforward manner in which data enter the forecast (11:8). Therefore, if forecasting is performed several times, over many items, exponential smoothing can be routinely accomplished. For unexpected sudden changes in the demand pattern, the estimator is unbiased in the long run; but for steadily increasing demands the estimator is biased because the forecast lags behind the demand (11:9).

Double exponential smoothing is similar to single exponential smoothing and the conclusions can be extended to any order of smoothing. The single smoothed value of the data will increase to the value of theta in response to the data input, while the response of the double smoothed value is theta squared (Θ^2). The order of smoothing is based on the choice of the degree of the polynomial

model that is to represent the data and the subsequent selection of a smoothing constant for the respective order.

This smoothing constant controls the number of past observations that have any effect on the forecast. Flexibility of changing the constant should be considered to obtain stable forecasts from stable processes and forecasts that respond rapidly when the value of any coefficient appears to have changed greatly (11:9). Two values should be selected for the smoothing constant: one for stable conditions and a higher value for conditions of rapid change. A small value includes many observations; but for larger values, only recent data are included. With the higher order models, more coefficients must be estimated. Since more coefficients are needed, the number of past observations should also be increased to insure better coefficient estimators by using as many data points as necessary to satisfy the degrees of freedom requirement for the model.

The moving average method does not attempt to assess rate-of-change in the data points as a function of time. In other words, the technique only estimates the current level of a factor without regard for whether that factor is increasing or decreasing, making no attempts to adjust for trends. The forecasts with the moving average are always the same, regardless of the forecast lead time (number of time periods into the future for which the

current forecast is being made). Thus the moving average forecasts straight ahead. In contrast, the exponential smoothing method estimates both the current level of a factor and the current linear rate-of-change for the same order. Forecasts made are a linear function of the forecast lead time using these estimates. Exponential smoothing attempts to account for and to follow trends, and it can follow the direction of these trends by forecasting upwards, downwards or straight ahead (9:9-10).

Headquarters AFLC suggests that the double exponential smoothing method should be analyzed for possible AFLC use (5) and that the present D041 prediction method should also be compared against other more currently developed predictive techniques (6).

This thesis continues the research conducted by Captain Bruce R. Christensen and Mr. Gene J. Schroeder, who used simulated models (2:Ch.1) to conclude that the expected value of the distribution of forecast errors presently found in the D041 System was not zero (3:Ch.1-3). Their recommendation was to incorporate actual D041 data into the investigation of the bias produced by the single moving average forecast and other techniques such as time series analysis (3:37).

Areas of Investigation

There are two areas of investigation that provide the objectives for the proposed research:

1. To determine if the D041 System forecasts are biased.

2. To calculate, review and compare the forecast error of time series analysis methods to that of the D041 System to determine which of the techniques is the best, in terms of minimum error, to forecast failures of spare parts.

Research Question

What forecasting technique should the D041 inventory management system use to provide the most accurate forecasts?

Research Hypotheses

1. The use of the weighted moving average technique leads to biased forecasts in the AFLC material support system.

2. The use of the time series analysis technique leads to forecasts with significantly less bias than that of the D041 System.

CHAPTER II

RESEARCH METHODOLOGY

Population of Interest

This research focused upon the characteristics of the D041 forecasting technique, the technique currently used to create quarterly forecasts for 125,000 recoverable items in the Air Force inventory. Of these 125,000 items, approximately 45,000 items are forecast subjectively by the responsible item manager, rather than by the D041 System based on past demands (5). These items are excluded from consideration since they do not typify the statistical technique used in the D041. The population was further limited to the nine Federal Stock Classes listed below:

1560	Aircraft Structural
1615	Helicopter Components
1630	Wheel and Brake Components
2915	Engine Components
5841	Airborne Radar
5865	Electronic Countermeasure
5905	Resistors
5910	Capacitors
6615	Airborne Gyros

The selection of these classes was based upon the past history of inaccurate forecasts and consequential problems as recommended by Ms. Anita Clevenger of AFLC (5). Class 1560, Aircraft Structural, was specifically selected because of its stable demand pattern. The population was further limited by the requirement for eight years data necessary to examine the performance of the techniques over an adequate time period.

Definition of Variables

Within the D041 forecasting environment, approximately 20 variables interact to influence the requirements computation for spares. Examination of most of these variables is beyond the scope of this research. With the focus on the performance of the forecasting technique itself, only the following variables were considered (5):

1. Base reparable generations, i.e., the number of failures.

2. Organizational Field Maintenance (OFM) demand rate, i.e., the predicted ratio of future reparable generations to the predicted number of flying hours.

3. Operational Program, i.e., the number of flying hours for the spare in question.

4. Projected Operational Program, i.e., the number of flying hours forecast for future periods.

Data Requirements

Data used in this research consisted of 31 quarters of forecast data and 35 quarters of actual reparable generations for a single Master Stock Number (MSN). To obtain this data, three elements of data were collected for each of 31 MSNs over the time period FY 69-2 to FY 77-4. These data elements, as shown in Table 2.1, consist of the OFM demand rate, the base reparable generations and the past operational program. To obtain a forecast of units demanded, the OFM demand rate is multiplied by the projected operational program. However, the forecasts provided by AFLC were obtained by multiplying the OFM demand rate by the past operational program (e.g., actual hours flown). This data, then, does not reflect the actual D041 forecasts and, hence, any conclusions drawn concerning the biasedness of these forecasts is of questionable significance.

Data Collection

The required data was available from the D041 Tape Library (5). Computer programs had to be written to extract the required information from the D041 tapes and transfer it to a data file in the CREATE System. Appendix A describes this data retrieval in detail. Master Stock Numbers were initially selected according to the following edit criteria:

TABLE 2.1

SIGNIFICANT VARIABLES

Description of Variable	Data Source	Units of Data Measurement	Value Level	Measurement Scale
Base Reparable Generation	D041 Data Library	To nearest Unit	Discrete Infinite	Ratio
Organization Field Maintenance Demand Rate	D041 Data Library	To four decimal points	Discrete Infinite	Ratio
Past Operational Program	D041 Data Library	To nearest unit	Discrete Infinite	Ratio

1. Element is in one of the 9 classes previously defined.

2. Element is coded XD.

3. Element is forecast by the D041 Sytem, not by the IM.

The initial computer run resulted in 500 MSNs (Classes 1615, 1630, 2915, 5841, and 6615). Subsequent runs against the above edit criteria reduced the usable data to 31 MSNs, all in class 6615.

Research Approach

The stated purposes of this research are to analyze the performances of different techniques used for forecasting reparable generations and to compare their accurateness. The basic approach was: (1) to compare the D041 single moving average forecast with actual reparable generations for the same time period to determine the forecast bias, and (2) to compare the two methods (D041, and time series analysis) with each other to determine which technique offered the least amount of bias.

Testing the First Research Hypothesis

The first research hypothesis was: The use of the weighted moving average technique leads to biased forecasts in the AFLC materiel support system. This is to say that the expected value of the forecast error presently found

in the D041 System is significantly different than zero. The hypothesis may then be stated as:

$$H_0: \; E(e_\tau) = 0$$

$$H_1: \; E(e_\tau) \neq 0$$

where:

$E(e_\tau)$ is the expected value of the forecast error, for fixed lead time τ.

Each D041 forecast from quarter five (FY 70-2) to quarter 34 (FY 77-3) was compared to the actual reparable generations for quarter six (FY 70-3) to quarter 35 (FY 77-4). The forecast error associated with each time period, for each Master Stock Number was calculated as:

$$e_\tau(t) = \hat{g}_\tau(t) - g(t) \qquad \text{(Equation 5)}$$

where:

$e_\tau(t)$ is the error term associated with (t), a lead time of τ,

$\hat{g}_\tau(t)$ is the forecast for period t made τ periods earlier, and

$g(t)$ is the actual reparable generations in period t.

The final data pattern consisted of four error distributions (one for lead times of 1, 2, 3, and 4 quarters) for each Master Stock Number. The data points were the error $[e_\tau(t)]$ values for t = 1, 2, 3, ... τ for a fixed lead time, τ.

Table 2.2 should clarify the explanation of forecasts made for various time periods for lead times one and two (3:20).

The first research hypothesis was designed to determine if the D041 forecasting method is biased. The expected value of each error distribution for a fixed lead time was calculated according to

$$E(e_\tau) = \sum_{t=1}^{n} [\hat{g}_\tau(t) - g(t)] \qquad \text{(Equation 6)}$$

where:

$E(e_\tau)$ is the expected value of the forecast error made for lead time τ,

$\hat{g}_\tau(t)$ is the forecast reparable generations for period t with lead time τ,

$g(t)$ is the actual reparable generation in period t, and

n is the number of data points in the distribution.

The hypothesis was then tested for each error distribution. Rejection of the null hypothesis means that the D041 forecast technique is biased (13).

A computer program was written to compute the forecast errors, and an SL library program (SIMFIT) was used to determine the statistic properties of these errors.

TABLE 2.2

EXAMPLE DETERMINATION OF FORECAST ERRORS FOR $\tau=1$ AND $\tau=2$

Lead Time τ	Month 1	2	3	4	5	6	7
1	$\hat{g}_1(2)$	$\hat{g}_1(3)$	$\hat{g}_1(4)$	$\hat{g}_1(5)$	$\hat{g}_1(6)$	$\hat{g}_1(7)$	$\hat{g}_1(3)$
		$g(2)$	$g(3)$	$g(4)$	$g(5)$	$g(6)$	$g(7)$
2	$\hat{g}_2(3)$	$\hat{g}_2(4)$	$\hat{g}_2(5)$	$\hat{g}_2(6)$	$\hat{g}_2(7)$	$\hat{g}_2(8)$	$\hat{g}_2(9)$
			$g(3)$	$g(4)$	$g(5)$	$g(6)$	$g(7)$

NOTE: $\hat{g}_\tau(t)$ is the τ-period forecast for the month t made in month $t-\tau$.

$g(t)$ is the actual number of generations for month t.

The one-month forecast error for month 2 is $e_1(2)=\hat{g}_1(2)-g(2)$.

The one-month forecast error for month 3 is $e_2(3)=\hat{g}_2(3)-g(3)$.

Testing the Second Research Hypothesis

The second hypothesis states: Use of the time series analysis techniques leads to forecasts with significantly less bias than that of the D041 System. To obtain a basis for comparison, forecasts were made from the same data base and lead times using SL library program TCAST. These forecasts were compared to the actual reparable generations for the period and the resulting errors were calculated according to Equation 5. The expected value for each distribution was then calculated according to Equation 6 and tested with the following hypothesis:

$$H_0: \quad E(e_\tau) = 0$$

$$H_1: \quad E(e_\tau) \neq 0$$

As with the first hypothesis, SL library program SIMFIT was used to compute the statistical properties of these errors. If the statistical test resulted in the rejection of the null hypothesis, it was inferred that the tested forecasting technique was biased. Conversely, if the null hypothesis could not be rejected, the inference was that the tested forecasting technique is not biased.

The expected values of the error distributions obtained from the two forecasting techniques were tested for significant statistical difference according to the following hypothesis:

$$H_0: \ |E(e_\tau)|_{D041} < |E(e_\tau)|_{TCAST}$$

$$H_1: \ |E(e_\tau)|_{D041} \geq |E(e_\tau)|_{TCAST}$$

If the statistical test results in the rejection of the null hypothesis, the time series (TCAST) forecasting technique is inferred to be more accurate than the D041 technique. Conversely, if the null hypothesis cannot be rejected, the inference is that there is no significant difference between the techniques.

List of Assumptions

1. The D041 forecasting procedures have been applied consistently through the period of time examined by this research.

2. The error terms for a specific lead time are statistically independent.

3. Forecasting errors are normally distributed.

List of Limitations

The research was limited to the forecasting techniques as applied to a subset of reparable items. Extrapolation to forecasting for other non-reparable items may require additional research.

CHAPTER III

FINDINGS AND ANALYSIS

The D041 Forecasting Method

The D041 forecasting method was investigated to determine if the forecast was biased. The forecast error distributions and their statistics were computed by computer programs for lead times of one, two, three, and four quarters (refer to Table D.1). For this particular MSN (661500735893), the null hypothesis could not be rejected at any reasonable confidence level for any of the four lead times examined, inferring that the D041 forecasting technique is unbiased for these data.

The graph plots (Figures C.9 through C.12) show the error distribution to approximate rather flat normal curves which are in fact very close to uniform distribution curves.

The TCAST Forecasting Method

The exponential smoothing forecasting method (TCAST) was investigated to determine if it produced forecasts which were biased. The distribution of forecast errors and its statistics were computed for lead times of one, two, three, and four (refer to Table D.2).

The TCAST model was optimized for each forecast made. Nearly 72 percent of the 102 forecasts made were

optimized with third order exponential smoothing, which takes into account the quadratic rate of change in the single exponentially smoothed average. Third order exponential smoothing normally results in more responsive forecasting than first or second order.

Similarly, larger alpha (smoothing constant) values usually result in more responsive forecasting, but in these data, 86 percent of the 102 forecasts were optimized with smoothing constants of .1 or .2 (refer to Table 3.1).

The null hypothesis could not be rejected at any reasonable level of confidence for any of the lead times of one, two, or three, inferring that the TCAST method of forecasting is unbiased for these data. However, for a lead time of four quarters, the null hypothesis could be rejected with 87 percent confidence, inferring that the TCAST method of forecasting, for a lead time of four quarters, is biased for these data.

The graph plots (Figures C.13 through C.16) of the error distributions approximate rather flat normal curves which are, in fact, very close to uniform distribution curves.

Comparison of the Two Forecasting Methods

The statistics of the D041 and the TCAST forecasting methods were compared to determine if the TCAST method offered less bias than the D041. The null hypothesis could

TABLE 3.1

CHARACTERISTICS OF TCAST FORECASTS

	Smoothing Constants							Type Smoothing		
Lead Time	.1	.2	.3	.4	.5	.6	.8	1	2	4
1	12	11	2			1	1	5	7	15
2	20	4	1	1				2	4	20
3		20	1	1	1			4	5	16
4	4	17	1	1			3	1	1	22
Totals	36	52	5	3	1	1	4	12	17	73

not be rejected with any reasonable confidence for any of the four lead times, inferring that there is no statistically significant difference in the expected values of the forecast errors for these two methods.

For all four lead times, the D041 forecasting method produced positive mean error values, inferring a somewhat consistent tendency to over-forecast. However, the TCAST method produced negative forecast error means for lead times one, three and four, inferring a tendency to under-forecast.

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The first research hypothesis stated that the use of the weighted moving average forecasting technique by the AFLC material support system led to biased forecasts. Because of the nature of the forecasts provided by AFLC, no conclusions can be reached concerning the biasedness of the D041 forecasting technique.

The second research hypothesis stated that the use of time series analysis technique would lead to significantly more accurate forecasts. Again, no firm conclusions can be stated regarding differences in accuracy between the two techniques. However, the TCAST forecasts were statistically unbiased and made no use of "after the fact" information as did the D041 forecasts. Also, the variance of the distribution of forecast errors for the TCAST technique was substantially less than the variance associated with the distribution of forecast errors for D041. This smaller variance means that the risk associated with using the TCAST forecast is less than that associated with using the D041 method.

Recommendations

Recommendations for further research include the following:

1. Research should be conducted using a larger variety of items. The data needed for this research is available in AFIT/CREATE Library under permanent D041 file.

2. The future program forecasting procedures and their ramifications should be studied. The projected flying hours (future program) are a driving force in the calculations to determine how many reparable assets of a given type will be required.

3. The Box and Jenkins forecasting technique should be investigated as a possible better forecasting method. This method should be compared to both the D041 results and the exponential smoothing time series results in this thesis.

4. The thesis results obtained from generated data by Captain Bruce Christensen and Mr. Gene Schroeder should be compared to the results of this thesis and any other techniques studied using real data.

APPENDICES

APPENDIX A

D041 DATA BANK DATA RETRIEVAL

The Current D041 Data Bank consists of approximately 330 magnetic tapes containing a staggering volume of historical information. It is in fact this volume which greatly complicates actual usage of the available data. In order to ferret out the bits of information pertinent to the issue at hand, hours of computer time were consumed in a computer search through the information.

In acquiring the data for this research effort, much time was dedicated to locating a knowledgeable person to explain system access procedures. Ms. Anita Clevenger of the Policy and Systems Division, HQ AFLC and Ms. Virginia Thomas of the CREATE Application Support Group were able to jointly and cooperatively furnish the required guidance. Ms. Thomas can furnish copies of the quarterly D041 Data Bank control ledger and the file format for each record.

The first set of problems encountered involving learning the use of tapes. A set of permanent tapes was secured through the use of System NEWTAPE. In order to preclude confusion and the inadvertent destruction (write-over) of one of the data tapes, a control log was used. For each program run the numbers and labels of the tapes read from, and written to, were recorded in this control log. A CARDIN NOSLEW control card was used immediately

prior to defining the "write to" tape in order to suppress any carriage control format instruction and therefore to obtain accurate "read" and "write" actions. Some of the D041 tapes are in marginal condition, which occasionally caused a run to abort with an irrecoverable input error. In each case, running the same program again after requesting special assistance of the operator resulted in a satisfactory run. Should this have failed, Ms. Thomas could have requested the reconstruction of the defective tape.

Program design incorporated the minimum number of tapes for each single run because of the limited number of tape drives (14) available on the CREATE System. If a single run required more than three tape drives, some delay was experienced. Several smaller runs rather than one large one were preferred.

In this research effort, the basic programming approach was to run the program against the first available data to arbitrarily select 900 Master Stock Numbers (MSNs) according to certain criteria, and write them to a data tape. The next run read these MSNs from the data tape, read through the next quarter's data tapes until the MSNs and desired list of information matched, and then wrote all of that information to another data tape. The following run read that information, read the next quarter's information, and wrote all the desired information to a third data tape. In other words, all the desired

information was transferred back and forth through each consecutive run. From this, it is obvious that runs had to be made in sequence. From discussions with the computer operator, it was learned that a CARDIN MSG1 control card could be used to instruct the operator to run that program only after the completion of a previous run. Therefore, an entire series of runs could be entered at one time. Preparing the runs in sequence led to the fact that prior to quarter 74-3, only first and third quarter data was retained in the Data Bank. After 74-3, data was retained for each quarter.

Beginning with quarter 75-4, MSNs became National Stock Numbers (NSNs) including the "00" (e.g., 6615003147504). Prior to 75-4 MSNs were really Federal Stock Numbers (FSNs) without the 00 (e.g., 66153147504). In order to make this transition in the series of runs, a conversion program was written to read the information already collected from a data bank and write it back to another data tape, inserting the 00 with a format statement. See Figure A.1 for a copy of this program.

In order to retrieve the data necessary for this research, three specific pieces of information were required, for each quarter, for an unknown number of MSNs. The OFM demand rate is available on the 01 record; the base reparable generations are available from the 03 record; and the past program is available from the 11 record.

The first run selected the initial set of (in this case) Federal Stock Numbers: 100 in each of five classes. The only other criteria were a requirement for existing data in the first quarter (70-2) and a computer made forecast for that quarter (card column 090 of the 01 record should be blank). An "E" in that card column would indicate a manipulated forecast. The program (Figure A.2) was run against the 01 record in quarter 70-2, which consisted of three tapes. These tapes appeared to be in stock number sequence. Results were 500 Federal Stock Numbers and the associated OFM demand rate for that quarter. This information was then written to a tape which in turn provided the basis for the run against the next quarter's data.

These runs against quarter 71-1 and subsequent quarters were made with the program in Figure A.3, which is the final run against quarter 77-4. This series of runs retrieved the OFM demand rate for each of the stock numbers remaining in the data sample. Since stock numbers were eliminated when no data was found or when a manual forecast was made, the number of stock numbers in the sample rapidly decreased from 500 to 46 with the final run.

With the demand rate data in hand, the next runs were made against the 03 and 11 records to obtain the past program and reparable generations data. The records show in the D041 Data Bank Control Ledger as only the 03 record, but the 03 through 11 records are carried on those tapes.

Sequence appears to be by Air Logistics Center, then stock number, then record type. Since eight quarters of data are carried on each quarter's records, it was necessary only to run against the 71-1, the 72-3, the 74-3, the 76-3 and the 77-4 tapes to obtain a full set of data for the stock numbers in the data sample. A sample of the program can be seen in Figure A-4.

Programming logic for this series was similar to that used for obtaining the OFM demand data. The end results were 22 quarters of OFM demand data (because of the missing quarters) on one tape and 35 quarters of past program and reparable generation data on the second tape. To mesh them together, compute the forecast and write all the data to a permanent data file, another program was written (Figure A.5). As the data was read from the tapes prior to adjusting, the quarters did not match. The data for a sample MSN appeared as in Table A.1. The missing OFM demand rates were filled in by straight line averaging the nearest actual demand rates. The limitations of this step were recognized, but it was deemed more valuable to compute the statistics for a larger sample of error points than to rely on strictly actual available data. Since no demand rates were available for the first four quarters (FY 69-2 through FY 70-1) no forecasts were analyzed for those quarters.

The end result of this program run was a usable stream of 35 quarters of data. The full data file for all 31 remaining stock numbers is established as a permanent file under the name D041. This file is accessible for other potential uses. The data for the stock number examined in this research is tabulated in Table A.2.

The actual data points to be examined in this research were the errors of the forecast. A computer program (Figure A.6) to read the D041 data (forecast and reparable generations) and compute the forecast errors for lead times one, two, three, and four (Table A.3) was accordingly written.

Time became one of the largest problems in obtaining this data file. The programs themselves normally required 15 to 35 minutes of computer time each. When this requirement is combined with the tape drive requirements and sequencing requirements, a data retrieval project becomes a formidable task requiring a significant number of calendar days to complete. The situation is complicated by computer down-time and the fact that jobs this large are only run at night and on weekends. Once the tape and formats were identified, writing and running the set of programs in this appendix required approximately six weeks of continuous daily runs.

```
C     FIGURE A.1 FSN/MSN CONVERSION PROGRAM
C
C
##N,R(SL)
$:IDENT:WP1190,AFITSL    77A  BRANTLEY LOREMAN
$:OPTION:FORTRAN,NOMAP
$:FORTY:NFORM,NLNO
C
C  PROGRAM FSN/MSN CONVERSION
C
C  THIS PROGRAM CONVERTS FEDERAL STOCK NUMBERS TO
C  NATIONAL STOCK NUMBERS.
C
 CHARACTER FIIN*11(70),FN*11,DC*1
 INTEGER FSC(70),CLASS,Q,QT,QTR
 DIMENSION OFMDR(70,14)
C
C  READ IN THE VALUES FOR THE TOTAL NUMBER OF MSN.
C
 READ 800,NUM
 800 FORMAT (V)
C
C  SET THE QUARTER NUMBER BEFORE EACH RUN.
C
 Q=14
 DO 1120 J=1,NUM
C
C  READ THE MSN AND DEMAND DATA FROM THE DATA TAPE.
C
 READ (16,1000,END=1220) FSC(J),FIIN(J)
 1000 FORMAT (I4,A11)
 DO 1090 QTR=1,Q-1
 READ (16,1010,END=1220) OFMDR(J,QTR)
 1010 FORMAT (F6.4)
 1090 CONTINUE
 1120 CONTINUE
C
C  NOW PRINT THE NSN'S AND WRITE THEM TO TAPE.
C  CONVERSION IS DONE BY FORMATTING IN A 00.
C  THE NEXT RUN WILL INCLUDE THE 00 IN ITS READ FORMAT
C  (A11) , COMPENSATED FOR WITH A 2X AFTER THE FIIN.
C
 1220 ITP=NUM
 DO 1250 J=1,ITP
 PRINT 1230,FSC(J),FIIN(J)
 1230 FORMAT (1X,I4,1X,2H00,1X,A11)
 WRITE (17,1240,END=1270) FSC(J),FIIN(J)
 1240 FORMAT (I4,2H00,A11)
 DO 1248 QTR=1,13
 PRINT 1245,OFMDR(J,QTR)
 1245 FORMAT (11X,F6.4)
 WRITE (17,1247,END=1270) OFMDR(J,QTR)
 1247 FORMAT (F6.4)
 1248 CONTINUE
```

```
      125Ø CONTINUE
      PRINT 126Ø, NUM
      126Ø FORMAT (//1X,41HTHE NUMBER OF STOCK NUMBERS
     & REMAINING IS ,I2)
      127Ø CONTINUE
C
      STOP
      END
$:EXECUTE
$:LIMITS:5,15K
$:DATA:I*
 52
$:TAPE:16,XID,,71988,,DATAFILE2
$:FFILE:17,NOSLEW
$:TAPE:17,AID,,7187Ø,,DATAFILE1/RING
$:ENDJOB
```

```
C          FIGURE A.2 FSN SELECTION PROGRAM
C
C
##N,R(SL)
$:IDENT:WP1190,AFITSL   77A  BRANTLEY  LOREMAN
$:OPTION:FORTRAN,NOMAP
$:FORTY:NFORM,NLNO
C
C  PROGRAM  SELECT
C
C  PROGRAM SELECTS 100 FEDERAL STOCK NUMBERS IN
C  CLASSES 1530,1615,1630,2915,5841,5865,5905,5910,
C  AND 6615 FROM THE DATA BANK AT AFLC.
C
C  TO BE RUN AGAINST THE 70-2 RECORD.
C
 CHARACTER FN*11,FIIN*11,DRC*1
 INTEGER FSC,CLASS,CLAS(9)/1530,1615,1630,
&2915,5841,5865,5905,5910,6615/
 DIMENSION IPT(9),FSC(9,100),FIIN (9,100),OFMDR(9,100)
C
C  INITIALIZE THE TAPE DEVICE TO BE READ FROM.
C
 INT=13
 DO 1230 KS=1,120000
 GO TO 5
C
C  INCREMENT THE TAPE DEVICE AND DETERMINE IF ALL THE
C  TAPES HAVE BEEN READ.
C
 999 INT=INT+1
 IF (INT.GT.14) GO TO 1240
C
C  READ THE FEDERAL STOCK CLASS,FIIN, DEMAND RATE,
C  AND DEMAND RATE CODE FROM THE TAPE.  THE FSC AND
C  THE FIIN ARE SEPARATED IN ORDER TO COMPARE THE
C  CLASSES.
C
 5 READ (INT,1000,END=999) CLASS,FN,DR,DRC
 1000 FORMAT (4X,I4,A11,65X,F5.0,A1)
C
C  DIVIDE THE DEMAND RATE BY 10000 IN ORDER TO PLACE
C  THE DECIMAL POINT IN THE PROPER PLACE.
C
 DR=DR/10000.
C
C  DISCARD THE ITEM IF THE DEMAND CODE IS E.
C
 1050 IF (DRC.EQ.'E') GO TO 1230
C
C  DETERMINE IF THE CLASS IS ONE OF THE NINE DESIRED.
C  IF THERE ARE ALREADY 100 ITEMS SAVED IN THAT CLASS,
C  READ ANOTHER NUMBER.  OTHERWISE SAVE THE FSC, FIIN,
C  AND DEMAND RATE.
```

```
C
      IP=0
      DO 1125 J=1,9
      IF (CLASS.EQ.CLAS(J)) IP=J
 1125 CONTINUE
      IF (IP.EQ.0) GO TO 5
      IF (IPT(IP).EQ.100) GO TO 5
      IPT(IP)=IPT(IP)+1
      FSC(IP,IPT(IP))=CLASS
      FIIN(IP,IPT(IP))=FN
      OFMDR(IP,IPT(IP))=DR
      IFL=0
C
C  DETERMINE THE TOTAL NUMBER OF DATA POINTS COLLECTED.
C   IF 900 HAVE BEEN COLLECTED PRINT THEM AND WRITE
C   THEM TO A TAPE.
C
      DO 1225 J=1,9
      IFL=IFL+IPT(J)
      IF (IFL.GE.900) GO TO  1240
 1225 CONTINUE
 1230 CONTINUE
 1240 DO 1260 I=1,9
      IF (FSC(I,J).EQ.0) GO TO 1260
      DO 1257 J=1,100
      IF (FSC(I,J).EQ.0) GO TO 1260
      PRINT 1250,FSC(I,J),FIIN(I,J),OFMDR(I,J)
 1250 FORMAT (1X,I4,1X,A11,2X,F6.4)
      WRITE (16,1255,END=1280) FSC(I,J),FIIN(I,J),OFMDR(I,J)
 1255 FORMAT (I4,A11,F6.4)
 1257 CONTINUE
 1260 CONTINUE
 1270 CONTINUE
 1280 CONTINUE
C
      STOP
      END
$:EXECUTE
$:LIMITS:40
$:TAPE:13,X1D,,70460,,70-2 DDB01
$:TAPE:14,X2D,,70368,,70-2 DDB01
$:FFILE:16,NOSLEW
$:TAPE:16,A1D,,73671,,MSNDATA/RING
$:ENDJOB
```

```
C  FIGURE A.3 OFM DEMAND DATA RETRIEVAL PROGRAM
C
C
##N,R(SL)
$:IDENT:WP1190,AFITSL    77A  BRANTLEY LOREMAN
$:MSG1:MUST BE RUN AFTER SNUMB G506T PLEASE
$:OPTION:FORTRAN,NOMAP
$:FORTY:NFORM,NLNO
C
C  PROGRAM DEMAND
C
C  THIS PROGRAM SEARCHES THROUGH EACH QUARTER'S DATA
C  TO RECORD THE OFM DEMAND RATE.
C
 CHARACTER FIIN*11(54),FN*11,DC*1
 INTEGER FSC(54),CLASS,Q,QT,QTR
 DIMENSION OFMDR(52,22)
C
C  READ IN THE VALUES FOR THE TOTAL NUMBER OF MSN
C  IN EACH CLASS.
C
 READ 800,NUM
 800 FORMAT (V)
C
C  SET THE QUARTER NUMBER BEFORE EACH RUN.
C
 Q=22
C
C  INITIALIZE THE TAPE DEVICE TO BE READ FROM IN
C  THE D041 DATA BANK.
C
 INT=13
C
C  SET THE VALUE FOR THE VARIABLE REPRESENTING THE
C  LAST TAPE DEVICE IN THE DATA BANK TO BE READ FROM
C  ON THIS RUN.
C
 IEN=13
C
C  INITIALIZE THE DEMAND DATA ARRAYH TO -1. IN ORDER
C  TO PROVIDE INDICATORS FOR DETERMINING WHICH MSN
C  WERE NOT MATCHED.
C
 DO 1120 J=1,NUM
 OFMDR (J,Q)=-1.
C
C  READ THE MSN AND DEMAND DATA FROM THE DATA TAPE.
C
 READ (16,1000,END=1220) FSC(J),FIIN(J)
 1000 FORMAT (I4,A11)
 DO 1090 QTR=1,Q-1
 READ (16,1010,END=1220) OFMDR(J,QTR)
 1010 FORMAT (F6.4)
 1090 CONTINUE
```

```
 1120 CONTINUE
C
C  SEARCH THRU THIS QUARTER'S DATA AND READ THE FSC,
C  FIIN, OFM DEMAND RATE, AND DEMAND CODE.
C
 DO 1210 INDX=1,120000
 GO TO 1129
C
C  DETERMINE IF THE LAST AVAILABLE TAPE HAS BEEN READ.
C
 1125 INT=INT+1
 IF (INT.GT.IEN) GO TO 1220
 1129 READ (INT,1130,END=1125) CLASS,FN,DR,DC
 1130 FORMAT (4X,I4,A11,65X,F5.0,A1)
C
C  MATCH THE ITEM READ TO THE BASIC DATA LIST
C  PREVIOUSLY SAVED.  IF THE STOCK NUMBERS MATCH,
C  INCREMENT THE COUNTER (KNTR) TO TRACK THE NUMBER
C  OF DATA POINTS AND RECORD THE DEMAND DATA.  IF THE
C  STOCK NUMBER READ DOESN'T MATCH ANY IN THE DATA
C  LIST, READ ANOTHER NUMBER.
C
 IF (CLASS.NE.6615) GO TO 1210
 DO 1165 J=1,NUM
 IF (FN.NE.FIIN(J)) GO TO 1165
 KNTR=KNTR+1
C
C  IF THE DEMAND CODE IS E, DO NOT SAVE DEMAND DATA.
C  OTHERWISE, SAVE THE DEMAND DATA.
C
 IF (DC.NE.'E') GO TO 1160
 GO TO 1210
 1160 OFMDR(J,Q)=DR/10000.
 IF (KNTR.LT.NUM) GO TO 1210
 GO TO 1220
 1165 CONTINUE
C
 1210 CONTINUE
C
C  UPDATE THE FILE.  FIND EACH MSN WITH DEMAND DATA
C  STILL EQUAL TO -1. AND ELIMINATE IT BY ADJUSTING
C  THE FIINS FROM THAT POINT ON.  THEN DECREMENT THE
C  NUMBER OF MSN'S REMAINING IN THAT CLASS AND ADJUST
C  ALL THE DEMAND DATA COLLECTED THUS FAR TO MAINTAIN
C  ALIGNMENT.
C
C  PRINT THE DATA AND WRITE IT BACK TO THE TAPE.
C
 1220 ITP=NUM
 DO 1250 J=1,ITP
 PRINT 1230,FSC(J),FIIN(J)
 1230 FORMAT (1X,I4,1X,A11)
 WRITE (17,1240,END=1270) FSC(J),FIIN(J)
 1240 FORMAT (I4,A11)
```

```
DO 1248 QTR=1,Q
PRINT 1245,OFMDR(J,QTR)
1245 FORMAT (11X,F6.4)
WRITE (17,1247,END=1270) OFMDR(J,QTR)
1247 FORMAT (F6.4)
1248 CONTINUE
GO TO 1250
1250 CONTINUE
PRINT 1260, NUM
C  1260 FORMAT (//1X,41HTHE NUMBER OF STOCK NUMBERS
& REMAINING IS ,I2)
1270 CONTINUE
C
STOP
END
$:EXECUTE
$:LIMITS:30,15K
$:DATA:I*
51
$:TAPE:13,X1D,,73512,,77-4 DDB01
$:TAPE:16,X2D,,73739,,DATAFILE7
$:FFILE:17,NOSLEW
$:TAPE:17,A1D,,70846,,DATAFILES/RING
$:ENDJOB
```

```
1000C  FIGURE A.4 PAST PROGRAM/REPARABLE GENERATION
1010C             DATA RETRIEVAL PROGRAM
1020C
1030C
1040##S,R(SL) :,8,16
1050$:MSG1:MUST BE RUN AFTER SNUMB M163T PLEASE
1060$:IDENT:WP1190,AFITSL    77A  BRANTLEY LOREMAN
1070$:OPTION:FORTRAN,NOMAP
1080$:FORTY:NFORM,NLNO
1090C
1100C  PROGRAM PAST PROGRAM/REPARABLE GENERATION
1110C
1120C  THIS PROGRAM SEARCHES THROUGH EACH QUARTER'S DATA
1130C  TO RECORD THE PAST OPERATIONAL PROGRAM AND
1140C  REPARABLE GENERATIONS FOR EACH MSN IN THE DATA
1150C  LIST.
1160C
1170 CHARACTER FIIN*11(46),FN*11,DUMMY*5(24)
1180 DIMENSION PSTPRG(46,35),RPGN(46,35),OFMDR(46,35),
1190&FRCST(46,35)
1200 DIMENSION PSTPRG(46,35),RPGN(46,35),RGPP(24),RGPPQ(8)
1210C
1220C  INITIALIZE THE TAPE DEVICE TO BE READ FROM IN THE
1230C  DATA BANK.
1240C
1250 INT=12
1260C
1270C  SET THE VALUE FOR THE VARIABLE REPRESENTING THE
1280C  LAST TAPE DEVICE IN THE DATA BANK TO BE READ FROM
1290C  ON THIS RUN.
1300C
1310 IF (PSTPRG(I,J).EQ.-1..OR.RPGN(I,J).EQ.-1.)
1320&MSN(I)='0'
1330 IEN=12
1340C
1350C  READ IN THE QUARTER AND NUMBER OF MSN.
1360C
1370 Q=35
1380 NUM=46
1390C
1400C  INITIALIZE THE PAST PROGRAM OR REPARABLE GENERATION
1410C  TO -1. TO PROVIDE INDICATORS FOR UNMATCHED MSN'S.
1420C
1430 DO 1280 NSN=1,46
1440 DO 1120 J=1,NUM
1450 OFMDR(NSN,36-I)=OFMDR(NSN,23-I)
1460 RPGN(J,Q)=-1.
1470C
1480 OFMDR(NSN,22-I)=(OFMDR(NSN,23-I)+OFMDR(NSN,21-I))/2.
1490C
1500 OFMDR(NSN,7)=OFMDR(NSN,6)=(OFMDR(NSN,8)+
1510&OFMDR(NSN,5))/2.
1520 1000 FORMAT (I4,A11)
1530 OFMDR(NSN,5)=OFMDR(NSN,1)
```

```
READ (16,1010,END=4000)PSTPRG(J,K),RPGN(J,K)
OFMDR(NSN,K)=.9999
1110 CONTINUE
FRCST(NSN,J)=OFMDR(NSN,J)*PSTPRG(NSN,J+1)
I=NSN
IF (NSN(I).EQ.'0') GO TO 1280
C
C
DO 1490 INDX=1,260000
GO TO 1140
C
C  DETERMINE IF THE LAST AVAILABLE TAPE HAS BEEN READ.
C
1135 INT=INT+1
IF (INT.GT.IEN) GO TO 3000
1140 READ (INT,1170,END=1135)RT,CLASS,FN,(DUMMY(IMNTH
&),IMNTH=1,24)
1170 FORMAT (I2,2X,I4,A11,2X,24A5)
IF (CLASS-6615) 1140,1171,1140
1171 GO TO (1140,1140,1200,1140,1140,1140,1140,1140,
&1140,1140,1200),RT
C
C  MATCH THE ITEM READ TO THE BASIC DATA LIST
C  PREVIOUSLY SAVED.  IF THE STOCK NUMBERS MATCH,
C  INCREMENT THE COUNTER (KNTR) TO TRACK THE NUMBER
C  OF DATA POINTS.  IF THE STOCK NUMBER READ DOESN'T
C  MATCH ANY IN THE DATA LIST, READ ANOTHER NUMBER.
C
1200 DO 1470 J=1,NUM
IF (FN.NE.FIIN(J)) GO TO 1470
KNTR=KNTR+1
C
C  SEPARATE THE MONTHLY DATA INTO QUARTERS BY ADDING
C  THE APPROPRIATE MONTHLY DATA TOGETHER.
C
MQ=-2
DO 1468 QTR=Q-4,Q
RGPPQ(QTR)=0.
MQ=MQ+3
DO 1460 MNTH=MQ,MQ+2
IF (DUMMY(MNTH).EQ.'*****') GO TO 1140
DECODE (DUMMY(MNTH),1453)RGPP(MNTH)
1453 FORMAT(F5.0)
RGPPQ(QTR)=RGPPQ(QTR)+RGPP(MNTH)
1460 CONTINUE
IF (RT.NE.03) GO TO 1465
RPGN(J,QTR)=RGPPQ(QTR)
GO TO 1468
1465 PSTPRG(J,QTR)=RGPPQ(QTR)
1468 CONTINUE
IF(KNTR.LT.2*NUM) GO TO 1140
GO TO 3000
1470 CONTINUE
1490 CONTINUE
```

```
3000 DO 3500 J=1,NUM
PRINT 3010, FSC(J),FIIN(J)
3010 FORMAT (/,I4,1X,A11)
WRITE (17,3020,END=4000) FSC(J),FIIN(J)
3020 FORMAT (I4,A11)
DO 3200 QTR=1,Q
PRINT 3100, PSTPRG(J,QTR),RPGN(J,QTR)
3100  FORMAT (11X,F7.0,5X,F7.0)
WRITE (17,3120,END=4000) PSTPRG (J,QTR),RPGN(J,QTR)
3120 FORMAT (F7.0,F7.0)
3200 CONTINUE
3500 CONTINUE
4000 CONTINUE
STOP
END
$:EXECUTE
$:LIMITS:60,40K
$:TAPE:12,X1D,,71948,,77-4 DDB03
$:TAPE:16,X2D,,76210,,DATAFILE5
$:FFILE:17,NOSLEW
$:TAPE:17,A1D,,73613,,DATAFILE9/RING
$:ENDJOB
```

```
C      FIGURE A.5 DATA PREPARATION PROGRAM
C
C
##N,R(SL)
$:IDENT:WP1190,  AFIT/SL  77A  BRANTLEY LOREMAN
$:OPTION:FORTRAN,NOMAP
$:FORTY:NFORM,NLNO
C
C  PROGRAM DATA PREPARATION
C
C  THIS PROGRAM READS THE MASTER STOCK NUMBER, OFM
C  DEMAND RATE, BASE REPARABLE GENERATIONS, AND PAST
C  PROGRAM INFORMATION FROM THE FILE AND PERFORMS
C  CALCULATIONS NECESSARY TO TRANSFORM THEM INTO A
C  DATA STREAM FOR ANALYSIS.
C
 CHARACTER FIIN*11(46),MSN1*15(46)
 INTEGER FSC(46)
 DIMENSION PSTPRG(46,35),RPGN(46,35),OFMDR(46,35),
&FRCST(46,35)
C
C  READ THE MSN, PAST PROGRAM, AND REPARABLE
C  GENERATION DATA FROM THE DATA TAPE.
C
 DO 1Ø4Ø I=1,46
 READ (12,1ØØØ,END=4ØØØ) FSC(I),FIIN(I)
 1ØØØ FORMAT (I4,A11)
 DO 1Ø3Ø J=1,35
  READ (12,1Ø1Ø,END=4ØØØ) PSTPRG(I,J),RPGN(I,J)
 1Ø1Ø FORMAT (2F7.Ø)
C
C  IF PAST PROGRAM OR REPARABLE GENERATION INFORMATION
C  IS NOT AVAILABLE (EQUALS -1.) THEN SET THAT FSC
C  EQUAL TO ZERO.
C
 IF (PSTPRG(I,J).EQ.-1..OR.RPGN(I,J).EQ.-1.)FSC(I)=Ø
 1Ø3Ø CONTINUE
 1Ø4Ø CONTINUE
 DO 1Ø8Ø L=1,46
C
C  READ THE MSN AND OFM DEMAND DATA FROM THE DATA TAPE.
C
 READ (13,1Ø5Ø,END=4ØØØ) MSN1(L)
 1Ø5Ø FORMAT (A15)
 DO 1Ø7Ø K=1,22
 READ (13,1Ø6Ø,END=4ØØØ) OFMDR(L,K)
 1Ø6Ø FORMAT (F6.4)
 1Ø7Ø CONTINUE
 1Ø8Ø CONTINUE
C
C  FOLLOWING SEGMENT OF PROGRAM MESHES THE 22 QUARTERS
C  OF OFM DEMAND DATA WITH THE 35 QUARTERS OF PAST
C  PROGRAM AND REPARABLE GENERATION DATA.
C  MISSING QUARTERS OF OFM DEMAND DATA WERE SIMULATED
```

```
C  BY STRAIGHTLINE AVERAGING THE VALUES ON EITHER SIDE.
C  FORECASTS WERE THEN COMPUTED BY MULTIPLYING THE OFM
C  DEMAND RATE BY THE PAST PROGRAM OF THE NEXT QUARTER.
C
DO 1280 NSN=1,46
DO 1100 I=1,14
OFMDR(NSN,36-I)=OFMDR(NSN,23-I)
1100 CONTINUE
JK=0
DO 1200 I=1,13,2
JK=JK+1
OFMDR(NSN,22-I)=(OFMDR(NSN,10-JK)+OFMDR(NSN,
&9-JK))/2.
IND=(22-I-5)/2
OFMDR(NSN,21-I)=OFMDR(NSN,IND)
1200 CONTINUE
OFMDR(NSN,7)=(OFMDR(NSN,2)+OFMDR(NSN,1))/2.
OFMDR(NSN,6)=OFMDR(NSN,7)
OFMDR(NSN,5)=OFMDR(NSN,1)
DO 1205 K=1,4
OFMDR(NSN,K)=.9999
1205 CONTINUE
DO 1210 J=5,34
FRCST(NSN,J)=OFMDR(NSN,J)*PSTPRG(NSN,J+1)
1210  CONTINUE
I=NSN
C
C  PRINT AND WRITE TO A PERMANENT FILE THE NSN,OFM
C  DEMAND RATE, PAST PROGRAM, FORECAST, AND REPARABLE
C  GENERATIONS FOR EACH QUARTER.
C  IF THE FSC EQUALS 0 (NO VALID DATA), THEN SKIP IT.
C
IF (FSC(I).EQ.0) GO TO 1280
PRINT 1230, FSC(I),FIIN(I)
1230 FORMAT (//,10X,3HNSN,2X,I4,A11,/)
WRITE (17,1240) FSC(I),FIIN(I)
1240 FORMAT (I4,A11)
PRINT 1245
1245 FORMAT (24X,4HPAST,20X,9HREPARABLE,/,1X,
&7HQUARTER,5X,5HOFMDR,5X,7HPROGRAM,5X,8HFORECAST,
&5X,11HGENERATIONS,//)
DO 1270 J=1,35
PRINT 1250,J,OFMDR(I,J),PSTPRG(I,J),FRCST(I,J),
&RPGN(I,J)
1250 FORMAT (4X,I2,6X,F6.4,5X,F6.0,5X,F8.4,8X,F6.0)
WRITE (17,1260) J,OFMDR(I,J),PSTPRG(I,J),FRCST(I,J),
&RPGN(I,J)
1260 FORMAT (I2,2X,F6.4,2X,F6.0,2X,F8.4,2X,F6.0)
1270 CONTINUE
1280 CONTINUE
4000 CONTINUE
STOP
END
$:EXECUTE
```

```
2080$:LIMITS:01,30K
2090$:TAPE:12,X1D,,73613,,DATAFILE9
2100$:TAPE:13,X2D,,73146,,DATAFILE6
2110$:FFILE:17,NOSLEW
2120$:PRMFL:17,W,S,77A84/D041
2130$:ENDJOB
```

TABLE A.1

D041 DATA

	Quarter	OFM Demand Rate	Past Program	Reparable Generations
1.	69-2	*	1016	28
2.	69-3	*	936	25
3.	69-4	*	914	23
4.	70-1	*	861	30
5.	70-2	.0336	816	24
6.	70-3	*	791	21
7.	70-4	*	693	32
8.	71-1	.0314	571	24
9.	71-2	*	580	22
10.	71-3	.0357	621	33
11.	71-4	*	548	21
12.	72-1	.0380	479	17
13.	72-2	*	497	32
14.	72-3	.0433	533	15
15.	72-4	*	502	17
16.	73-1	.0424	493	24
17.	73-2	*	577	17
18.	73-3	.0367	809	16
19.	73-4	*	928	27
20.	74-1	.0301	981	11
21.	74-2	*	663	14
22.	74-3	.0243	652	10
23.	74-4	.0235	435	11
24.	75-1	.0218	285	10
25.	75-2	.0213	364	10
26.	75-3	.0222	383	11
27.	75-4	.0202	392	7
28	76-1	.0247	384	15
29.	76-2	.0266	342	12
30.	76-3	.0283	379	8
31.	76-4	.0293	384	15
32.	77-1	.0300	342	12
33.	77-2	.0339	379	8
34.	77-3	.0335	335	11
35.	77-4	.0357	324	13

*Indicates missing data.

TABLE A.2

DATA AFTER PREPARATION

MSN 6615000735893

QUARTER	OFMDR	PAST PROGRAM	FORECAST	REPARABLE GENERATIONS
1	0.9999	1016.	0.	28.
2	0.9999	936.	0.	25.
3	0.9999	914.	0.	23.
4	0.9999	861.	0.	30.
5	0.0336	816.	26.5776	24.
6	0.0325	791.	22.5225	21.
7	0.0325	693.	18.5575	32.
8	0.0314	571.	18.2120	24.
9	0.0336	580.	20.8346	22.
10	0.0357	621.	19.5636	33.
11	0.0369	548.	17.6512	21.
12	0.0380	479.	18.8860	17.
13	0.0407	497.	21.6665	32.
14	0.0433	533.	21.7366	15.
15	0.0429	502.	21.1251	17.
16	0.0424	493.	24.4648	24.
17	0.0396	577.	31.9960	17.
18	0.0367	809.	34.0576	16.
19	0.0334	928.	32.7654	27.
20	0.0301	981.	19.9563	11.
21	0.0272	663.	17.7344	14.
22	0.0243	652.	10.5705	10.
23	0.0235	435.	6.6975	11.
24	0.0218	285.	7.9352	10.
25	0.0213	364.	8.1579	10.
26	0.0222	383.	8.7024	11.
27	0.0202	392.	7.7568	7.
28	0.0247	384.	8.4474	15.
29	0.0266	342.	10.0814	12.
30	0.0283	379.	10.8672	8.
31	0.0293	384.	10.0206	15.
32	0.0300	342.	11.3700	12.
33	0.0339	379.	11.3565	8.
34	0.0335	335.	10.8540	11.
35	0.0357	324.	0.	13.

```
1ØØØC  FIGURE A.6 DØ41 FORECAST ERROR COMPUTATION PROGRAM
1Ø1ØC
1Ø2ØC
1Ø3ØC  THIS PROGRAM ANALYZES THE DØ41 DATA AND COMPUTES
1Ø4ØC  THE ERROR ASSOCIATED WITH EACH FORECAST THROUGH
1Ø5ØC  LEAD TIMES ONE, TWO, THREE, AND FOUR.
1Ø6ØC
1Ø7Ø CHARACTER MSN*13
1Ø8Ø DIMENSION FRCST(35),RPGN(35),ERRDØ41(4Ø,4)
1Ø9ØC
11ØØC  READ FROM A FILE THE MASTER STOCK NUMBER, FORECAST,
111ØC  REPARABLE GENERATIONS FOR EACH QUARTER.
112ØC
113Ø CALL ATTACH(16,"77A84/DATDØ41;",3,1,,)
114Ø READ (16,9ØØ) LN,MSN
115Ø 9ØØ FORMAT (V)
116Ø DO 1ØØØ I=1,35
117Ø READ (16,9ØØ) LN,FRCST(I),RPGN(I)
118Ø 1ØØØ CONTINUE
119Ø DO 11ØØ I=5,34
12ØØ DO 1Ø9Ø J=1,4
121Ø IND=I+J
122Ø IF (IND.GT.35) GO TO 1Ø8Ø
123Ø ERRDØ41(I,J)=FRCST(I)-RPGN(IND)
124Ø GO TO 1Ø9Ø
125Ø 1Ø8Ø CONTINUE
126Ø 1Ø9Ø CONTINUE
127Ø 11ØØ CONTINUE
128Ø PRINT 111Ø
129Ø 111Ø FORMAT (34X,"TABLE A.3",//,24X,
13ØØ&"COMPUTED DØ41 FORECAST ERROR"/////)
131Ø PRINT 112Ø
132Ø 112Ø FORMAT (21X,4(2X,8HLEADTIME))
133Ø PRINT 113Ø
134Ø 113Ø FORMAT (27X,1H1,9X,1H2,9X,1H3,9X,1H4)
135Ø PRINT 1135
136Ø 1135 FORMAT (15X,7HQUARTER,3X,5HERROR,3(5X,5HERROR),//)
137Ø DO 116Ø I=5,34
138Ø PRINT 114Ø,I,ERRDØ41(I,1),ERRDØ41(I,2),
139Ø&ERRDØ41(I,3),ERRDØ41(I,4)
14ØØ 114Ø FORMAT (18X,I2,4(4X,F6.1),/)
141Ø 115Ø CONTINUE
142Ø 116Ø CONTINUE
143Ø STOP
144Ø END
```

TABLE A.3

COMPUTED D041 FORECAST ERROR

QUARTER	LEADTIME 1 ERROR	LEADTIME 2 ERROR	LEADTIME 3 ERROR	LEADTIME 4 ERROR
5	5.6	-5.4	2.6	4.6
6	-9.5	-1.5	0.5	-10.5
7	-5.4	-3.4	-14.4	-2.4
8	-3.8	-14.8	-2.8	1.2
9	-12.2	-0.2	3.8	-11.2
10	-1.4	2.6	-12.4	4.6
11	0.7	-14.3	2.7	0.7
12	-13.1	3.9	1.9	-5.1
13	6.7	4.7	-2.3	4.7
14	4.7	-2.3	4.7	5.7
15	-2.9	4.1	5.1	-5.9
16	7.5	8.5	-2.5	13.5
17	16.0	5.0	21.0	18.0
18	7.1	23.1	20.1	24.1
19	21.8	18.8	22.8	21.8
20	6.0	10.0	9.0	10.0
21	7.7	6.7	7.7	7.7
22	-0.4	0.6	0.6	-0.4
23	-3.3	-3.3	-4.3	-0.3
24	-2.1	-3.1	0.9	-7.1
25	-2.8	1.2	-6.8	-3.8
26	1.7	-6.3	-3.3	0.7
27	-7.2	-4.2	-0.2	-7.2
28	-3.6	0.4	-6.6	-3.6
29	2.1	-4.9	-1.9	2.1
30	-4.1	-1.1	2.9	-0.1
31	-2.0	2.0	-1.0	-3.0
32	3.4	0.4	-1.6	0.
33	0.4	-1.6	0.	0.
34	-2.1	0.	0.	0.

APPENDIX B

TIME SERIES FORECASTING DATA PREPARATION

The forecasting method used was that of the Honeywell Corporation TCAST computer program in the AFIT CREATE Library. This program reviews the exhibited characteristics of a variable and describes its behavior by performing an intrinsic analysis on discrete data. In the analysis each data point is split into base series, trends, seasonal, cyclical and erratic components. Base series are known historical data values which are considered constant over given periods of time; trend refers to the long-term growth or decay of the system; seasonal refers to regular annually recurring periodic fluctuations which are predictable; cyclical is a wave-like fluctuation about a trend which is not constant nor predictable; erratic refers to the unexplained or random variation that occurs for unknown reasons. After the analysis on each data component the results are combined and the forecasting model developed generates a forecast.

The forecast generation followed five objectives:

1. Evaluated trends in the historical data.

2. Dampened the erratic variations.

3. Responded to true changes in the physical process as they occurred.

4. Projected trends in future time periods.

5. Used program generated optimum forecast parameters to accomplish the previous four objectives.

A "signal," the deterministic part of the time series, consists of the long-term trend, cyclic and seasonal effects and this signal is separate from the random variation. This signal and the random variation projections are used together to determine a future process value. Logically these steps were followed to develop a signal:

1. Display the data and visually determine any obvious characteristics.

2. Remove any apparent growth or decay trends.

3. Remove any significant cyclical components.

4. Evaluate the residual trends of the original corrected data and determine their type and order of growth or decay.

5. Fit the residual trends to an appropriate program method: exponential smoothing.

6. Forecast for the future period using the appropriate programmed time series forecast model.

7. Continue to update the model as new data becomes available.

As updating continues various alphas are selected within the TCAST Program to give the smallest mean absolute deviation (MAD) of the forecast errors for each smoothing type. Generally, alphas will be between .01 and .3 for first

order smoothing and .3 to one for second or third order smoothing. After smoothing has been accomplished the residual left is due to random variations and these would produce errors in any forecast model.

Forecasts for this study were generated by truncating the TCAST program through the use of ASK function. Accordingly, all extraneous data was sent to a file dump while only the forecast information was asked for on the teletype, thereby decreasing the actual time for the teletype operation of TCAST. The actual operation of TCAST was easily accomplished by following the instructions that can be obtained from AFIT/CREATE Library.

The forecasts generated were obtained by using the first eight data points to establish a computational base for the first forecast, with additional data items input to continue forecasting into future periods. Forecasts were generated for lead times (number of periods in the future being forecasted) of one, two, three and four. Specifically, for lead time one, forecasts began in the ninth quarter and continued to the 35th quarter; for lead time two, forecasts began in the tenth quarter and continued to the thirty-fifth; for lead time three; forecasts began in the eleventh quarter and continued to the thirty-fifth quarter; and for lead time four fore-casts began in the twelfth quarter and continued to the thirty-fifth quarter. One complete TCAST run had to be made for

each needed forecast; i.e., the first run included the first eight data points to form the data base to forecast for the ninth period, the second run included the data base plus the influence of the ninth periods actual usage to forecast for the tenth period, and so forth. Each run continued to regenerate forecast for the past periods for which a forecast had already been extracted but these were disregarded and only the last period forecasted on each run was extracted.

After the forecasts were obtained for each quarter the type smoothing (first order, second order, or third order) was recorded, as was the alpha (optimal weighted value). Following this the actual reparable generations were subtracted from the forecasted values and this difference represented the error for each quarter. The error was rounded to one decimal place and both positive and negative values were obtained. (See Figure B.1 through B.4.) These differences represented the error distributions data base.

TABLE B.1

TCAST DATA FOR LEAD TIME ONE

Qtr.	Order Smoothing	Smoothing Constant	Forecast	Reparable Generations	Forecast Error
8	3	.2	25.453	24	
9	2	.8	19.429	22	3.5
10	1	.3	27.253	33	-13.6
11	3	.1	24.953	21	6.3
12	3	.1	22.370	17	8.0
13	1	.1	26.092	32	-9.6
14	3	.1	21.706	15	11.1
15	3	.1	19.830	17	4.7
16	1	.2	22.536	24	-4.2
17	3	.1	18.911	17	5.5
18	3	.1	17.407	16	2.9
19	3	.1	19.550	27	-9.6
20	3	.1	16.516	11	8.6
21	3	.1	15.026	14	2.5
22	3	.2	10.008	10	5.0
23	3	.2	8.8349	11	-1.0
24	3	.2	7.8006	10	-1.2
25	2	.2	8.6828	10	-2.2
26	2	.2	8.6299	11	-2.3
27	3	.1	6.7158	7	1.6
28	2	.2	9.3022	15	-8.3
29	1	.6	12.156	12	-2.7
30	3	.1	7.2936	8	4.2
31	2	.2	10.514	15	-7.7
32	2	.3	12.162	12	-1.5
33	2	.2	9.3827	8	4.2
34	1	.2	7.7847	11	-1.6
35				15	-5.2

TABLE B.2

TCAST DATA FOR LEAD TIME TWO

Qtr.	Order Smoothing	Smoothing Constant	Forecast	Reparable Generations	Forecast Error
9	1	.3	25.985		
10	3	.1	24.098	33	-7.0
11	3	.1	26.659	21	3.9
12	3	.1	24.756	17	9.7
13	3	.1	21.929	32	-7.3
14	3	.1	24.652	15	6.9
15	3	.1	21.242	17	7.7
16	3	.1	19.211	24	2.8
17	3	.1	19.950	17	2.2
18	3	.1	18.281	16	4.0
19	3	.1	16.672	27	-8.7
20	3	.1	19.081	11	5.7
21	3	.1	15.781	14	5.1
22	3	.1	14.195	10	5.8
23	3	.1	11.684	11	3.2
24	3	.1	10.096	10	1.7
25	3	.1	8.5976	10	.1
26	3	.1	7.5072	11	-2.4
27	3	.1	7.0772	7	.5
28	3	.1	5.5248	15	-7.9
29	3	.1	7.0390	12	-6.5
30	2	.2	9.2174	8	-1.0
31	2	.2	7.9214	15	-5.8
32	2	.2	10.175	12	-4.1
33	2	.2	10.491	8	2.2
34	1	.4	9.6932	11	- .5
35				13	-3.3

TABLE B.3

TCAST DATA FOR LEAD TIME THREE

Qtr.	Order Smoothing	Smoothing Constant	Forecast	Reparable Generations	Forecast Error
10	2	.5	25.117		
11	1	.8	22.638	21	4.1
12	2	.2	27.594	17	5.6
13	3	.2	23.838	32	-4.4
14	3	.2	17.109	15	8.8
15	3	.2	26.159	17	.1
16	3	.2	17.179	24	2.2
17	3	.2	13.819	17	.2
18	3	.2	18.207	16	-2.2
19	3	.2	15.177	27	-2.2
20	3	.2	12.870	11	4.2
21	3	.2	21.246	14	-1.1
22	3	.2	12.779	10	11.2
23	3	.2	10.619	11	1.8
24	3	.2	6.3872	10	.6
25	3	.2	5.2920	10	-3.6
26	3	.2	4.3943	11	-5.7
27	3	.2	4.4559	7	-2.6
28	3	.2	5.8945	15	-10.5
29	2	.2	5.1863	12	-6.1
30	2	.2	8.0304	8	-2.8
31	2	.2	8.6894	15	-7.0
32	1	.8	8.8621	12	-3.3
33	1	.8	13.772	8	.9
34	1	.4	10.338	11	2.8
35				13	-2.7

TABLE B.4

TCAST DATA FOR LEAD TIME FOUR

Qtr.	Order Smoothing	Smoothing Constant	Forecast	Reparable Generations	Forecast Error
11	3	.3	8.0450		
12	3	.3	18.625	17	-9.0
13	3	.2	30.163	32	-13.4
14	3	.2	23.476	15	15.2
15	3	.2	15.709	17	6.5
16	3	.2	26.359	24	-8.3
17	3	.2	15.927	17	9.4
18	3	.2	12.164	16	- .1
19	3	.2	17.436	27	-14.8
20	3	.1	16.967	11	6.4
21	3	.2	11.475	14	3.0
22	3	.1	18.112	10	1.5
23	3	.2	11.548	11	7.1
24	3	.2	9.1894	10	1.5
25	3	.2	4.4506	10	- .8
26	3	.2	3.4062	11	-6.6
27	3	.2	2.5908	7	-3.6
28	3	.2	2.8846	15	-12.4
29	3	.2	4.7567	12	-9.1
30	3	.2	2.5082	8	-3.2
31	3	.1	5.0361	15	-12.5
32	3	.1	5.5723	12	-7.0
33	2	.2	6.7258	8	-2.4
34	1	.4	8.5262	11	-4.3
35				13	-4.5

APPENDIX C

STATISTICS COMPUTATION

The statistics for the error distributions were computed using the LSS/SIMFIT program. The program fitted the error data points to an internally determined distribution type, and then provided the type distribution derived and the statistics as shown in Figures C.1 through C.8. These statistics were then used to perform Student's t tests on the null hypotheses.

The SIMFIT Program gave the uniform distribution as the predominate distribution fitting the data (smallest maximum error) for five of the eight error distributions. However, the histogram provided by SIMFIT empirically displayed the data in symetrical form. The normal distribution's maximum error was larger than the Uniform's, however, in testing for the Uniform the larger errors were not sufficient to reject the Uniform distribution at the 90 percent confidence level. But since empirical evidence must be weighted more heavily than theoretical, the normal distribution was accepted as being the predominant distribution, which supported the previous assumption that the forecast error was normally distributed. This can be more clearly seen in the graphs in Figures C.9 through C.16.

The slightly larger variance of the D041 forecasts can be easily seen in the graphs (Figure C.17 through C.24) which plot the forecast error over time.

```
THIS IS THE ERROR DISTRIBUTION

          SAMPLE STATISTICS

NUMBER OF VALUES IN LIMITS =      30.000

MINIMUM VALUE OF ALL DATA  =     -13.100

MAXIMUM VALUE OF ALL DATA  =      21.800

MODE OF DATA      =       -3.750

ARITHMETIC MEAN =          0.517

STD. DEVIATION  =          7.476

VARIANCE        =         55.897

VARIANCE / MEAN =        108.188

ESTIMATED SAMPLE MOMENTS ABOUT THE MEAN:

   3      276.4
   4      0.1167E 05


A3      0.696

IF A3 IS EQUAL TO ZERO, THE DISTRIBUTION IS SYMMETRICAL

A4      0.997

IF A4 IS NEGATIVE DISTRIBUTION HAS A FLAT TOP

IF A4 IS ZERO, DISTRIBUTION IS ALMOST NORMAL

IF A4 IS POSITIVE, DISTRIBUTION HAS A HIGH PEAK.

IF ANY PROBABILITY FUNCTIONS DO NOT FIT DATA
SUGGEST THAT YOU TRY THE FOLLOWING VALUES
      AMEN  =    -13.1000
      WIDTH =      3.8778
      NCELLS=     9
```

Figure C.1. Statistics Computations for D041 Forecasts in Lead Time One

```
THIS IS THE ERROR DISTRIBUTION

        SAMPLE STATISTICS

NUMBER OF VALUES IN LIMITS =       29.000

MINIMUM VALUE OF ALL DATA  =      -14.800

MAXIMUM VALUE OF ALL DATA  =       23.100

MODE OF DATA      =        0.750

ARITHMETIC MEAN =          0.883

STD. DEVIATION  =          7.908

VARIANCE          =       62.536

VARIANCE / MEAN =         70.842

ESTIMATED SAMPLE MOMENTS ABOUT THE MEAN:

   3        335.3
   4      0.1654E 05


A3      0.715

IF A3 IS EQUAL TO ZERO, THE DISTRIBUTION IS SYMMETRICAL

A4      1.536

IF A4 IS NEGATIVE DISTRIBUTION HAS A FLAT TOP

IF A4 IS ZERO, DISTRIBUTION IS ALMOST NORMAL

IF A4 IS POSITIVE, DISTRIBUTION HAS A HIGH PEAK.

IF ANY PROBABILITY FUNCTIONS DO NOT FIT DATA
SUGGEST THAT YOU TRY THE FOLLOWING VALUES
      AMEN  =    -14.8000
      WIDTH =      4.3563
      NCELLS=     9
```

Figure C.2. Statistics Computations for D041 Forecasts in Lead Time Two

```
THIS IS THE ERROR DISTRIBUTION

        SAMPLE STATISTICS

NUMBER OF VALUES IN LIMITS =       28.000

MINIMUM VALUE OF ALL DATA  =      -14.400

MAXIMUM VALUE OF ALL DATA  =       22.800

MODE OF DATA      =          0.750

ARITHMETIC MEAN =            1.650

STD. DEVIATION   =           8.662

VARIANCE         =          75.031

VARIANCE / MEAN =           45.473

ESTIMATED SAMPLE MOMENTS ABOUT THE MEAN:

   3       534.1
   4       0.2067E 05


A3      0.868

IF A3 IS EQUAL TO ZERO, THE DISTRIBUTION IS SYMMETRICAL

A4      0.949

IF A4 IS NEGATIVE DISTRIBUTION HAS A FLAT TOP

IF A4 IS ZERO, DISTRIBUTION IS ALMOST NORMAL

IF A4 IS POSITIVE, DISTRIBUTION HAS A HIGH PEAK.

IF ANY PROBABILITY FUNCTIONS DO NOT FIT DATA
SUGGEST THAT YOU TRY THE FOLLOWING VALUES
     AMEN  =    -14.4000
     WIDTH =      4.4286
     NCELLS=      8
```

Figure C.3. Statistics Computations for D041 Forecasts in Lead Time Three

```
THIS IS THE ERROR DISTRIBUTION

        SAMPLE STATISTICS

NUMBER OF VALUES IN LIMITS =        27.000

MINIMUM VALUE OF ALL DATA  =       -11.200

MAXIMUM VALUE OF ALL DATA  =        24.100

MODE OF DATA       =        0.750

ARITHMETIC MEAN =           2.178

STD. DEVIATION  =           9.069

VARIANCE        =          82.248

VARIANCE / MEAN =          37.767

ESTIMATED SAMPLE MOMENTS ABOUT THE MEAN:

   3       614.0
   4      0.2026E 05


A3      0.871

IF A3 IS EQUAL TO ZERO, THE DISTRIBUTION IS SYMMETRICAL

A4      0.230

IF A4 IS NEGATIVE DISTRIBUTION HAS A FLAT TOP

IF A4 IS ZERO, DISTRIBUTION IS ALMOST NORMAL

IF A4 IS POSITIVE, DISTRIBUTION HAS A HIGH PEAK.

IF ANY PROBABILITY FUNCTIONS DO NOT FIT DATA
SUGGEST THAT YOU TRY THE FOLLOWING VALUES
     AMEN  =    -11.2000
     WIDTH =      4.3580
     NCELLS=      8
```

Figure C.4. Statistics Computations for D041 Forecasts in Lead Time Four

```
THIS IS THE ERROR DISTRIBUTION

        SAMPLE STATISTICS

NUMBER OF VALUES IN LIMITS =       27.000

MINIMUM VALUE OF ALL DATA  =      -13.600

MAXIMUM VALUE OF ALL DATA  =       11.100

MODE OF DATA      =       5.250

ARITHMETIC MEAN =        -0.096

STD. DEVIATION   =        6.231

VARIANCE          =       38.827

VARIANCE / MEAN =      -403.207

ESTIMATED SAMPLE MOMENTS ABOUT THE MEAN:

   3        -70.11
   4         3299.


A3      -0.307

IF A3 IS EQUAL TO ZERO, THE DISTRIBUTION IS SYMMETRICAL

A4      -0.640

IF A4 IS NEGATIVE DISTRIBUTION HAS A FLAT TOP

IF A4 IS ZERO, DISTRIBUTION IS ALMOST NORMAL

IF A4 IS POSITIVE, DISTRIBUTION HAS A HIGH PEAK.

IF ANY PROBABILITY FUNCTIONS DO NOT FIT DATA
SUGGEST THAT YOU TRY THE FOLLOWING VALUES
      AMEN   =    -13.6000
      WIDTH =       3.0494
      NCELLS=      8
```

Figure C.5. Statistics Computations for TCAST Forecasts in Lead Time one

```
THIS IS THE ERROR DISTRIBUTION

        SAMPLE STATISTICS

NUMBER OF VALUES IN LIMITS =       26.000

MINIMUM VALUE OF ALL DATA  =       -8.700

MAXIMUM VALUE OF ALL DATA  =        9.700

MODE OF DATA      =        0.750

ARITHMETIC MEAN =          0.269

STD. DEVIATION  =          5.308

VARIANCE          =       28.174

VARIANCE / MEAN =      104.647

ESTIMATED SAMPLE MOMENTS ABOUT THE MEAN:

   3      -24.13
   4       1415.


A3     -0.171

IF A3 IS EQUAL TO ZERO, THE DISTRIBUTION IS SYMMETRICAL

A4     -1.072

IF A4 IS NEGATIVE DISTRIBUTION HAS A FLAT TOP

IF A4 IS ZERO, DISTRIBUTION IS ALMOST NORMAL

IF A4 IS POSITIVE, DISTRIBUTION HAS A HIGH PEAK.

IF ANY PROBABILITY FUNCTIONS DO NOT FIT DATA
SUGGEST THAT YOU TRY THE FOLLOWING VALUES
     AMEN  =      -8.7000
     WIDTH =       2.3590
     NCELLS=       8
```

Figure C.6. Statistics Computations for TCAST Forecasts in Lead Time Two

```
THIS IS THE ERROR DISTRIBUTION

          SAMPLE STATISTICS

NUMBER OF VALUES IN LIMITS =        25.000

MINIMUM VALUE OF ALL DATA  =       -10.500

MAXIMUM VALUE OF ALL DATA  =        11.200

MODE OF DATA       =        0.750

ARITHMETIC MEAN =          -0.516

STD. DEVIATION  =           5.231

VARIANCE        =          27.363

VARIANCE / MEAN =         -53.029

ESTIMATED SAMPLE MOMENTS ABOUT THE MEAN:

   3        26.82
   4        1903.


A3      0.199

IF A3 IS EQUAL TO ZERO, THE DISTRIBUTION IS SYMMETRICAL

A4     -0.242

IF A4 IS NEGATIVE DISTRIBUTION HAS A FLAT TOP

IF A4 IS ZERO, DISTRIBUTION IS ALMOST NORMAL

IF A4 IS POSITIVE, DISTRIBUTION HAS A HIGH PEAK.

IF ANY PROBABILITY FUNCTIONS DO NOT FIT DATA
SUGGEST THAT YOU TRY THE FOLLOWING VALUES
       AMEN   =    -10.5000
       WIDTH  =      2.8933
       NCELLS=       8
```

Figure C.7. Statistics Computations for TCAST Forecasts in Lead Time Three

```
THIS IS THE ERROR DISTRIBUTION

        SAMPLE STATISTICS

NUMBER OF VALUES IN LIMITS =      24.000

MINIMUM VALUE OF ALL DATA  =     -14.800

MAXIMUM VALUE OF ALL DATA  =      15.200

MODE OF DATA      =      -8.250

ARITHMETIC MEAN =        -2.558

STD. DEVIATION   =        7.834

VARIANCE         =       61.376

VARIANCE / MEAN =       -23.991

ESTIMATED SAMPLE MOMENTS ABOUT THE MEAN:

   3       168.8
   4       8503.


A3      0.374

IF A3 IS EQUAL TO ZERO, THE DISTRIBUTION IS SYMMETRICAL

A4     -0.542

IF A4 IS NEGATIVE DISTRIBUTION HAS A FLAT TOP

IF A4 IS ZERO, DISTRIBUTION IS ALMOST NORMAL

IF A4 IS POSITIVE, DISTRIBUTION HAS A HIGH PEAK.

IF ANY PROBABILITY FUNCTIONS DO NOT FIT DATA
SUGGEST THAT YOU TRY THE FOLLOWING VALUES
      AMEN  =    -14.8000
      WIDTH =      4.1667
      NCELLS=      7
```

Figure C.8. Statistics Computations for TCAST Forecasts in Lead Time Four

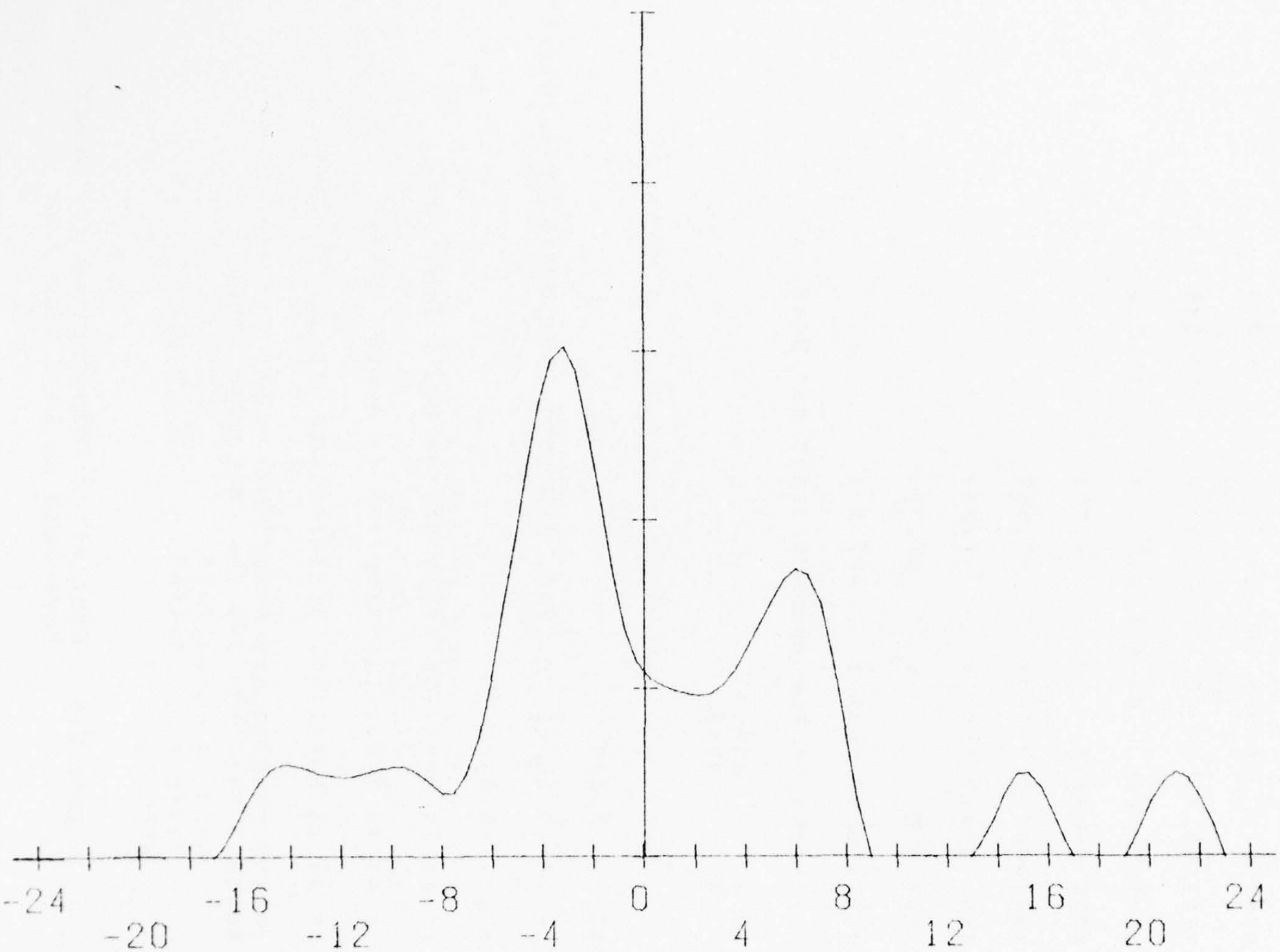

FIGURE C.9 D041 ERROR DISTRIBUTION FOR LEAD TIME 1

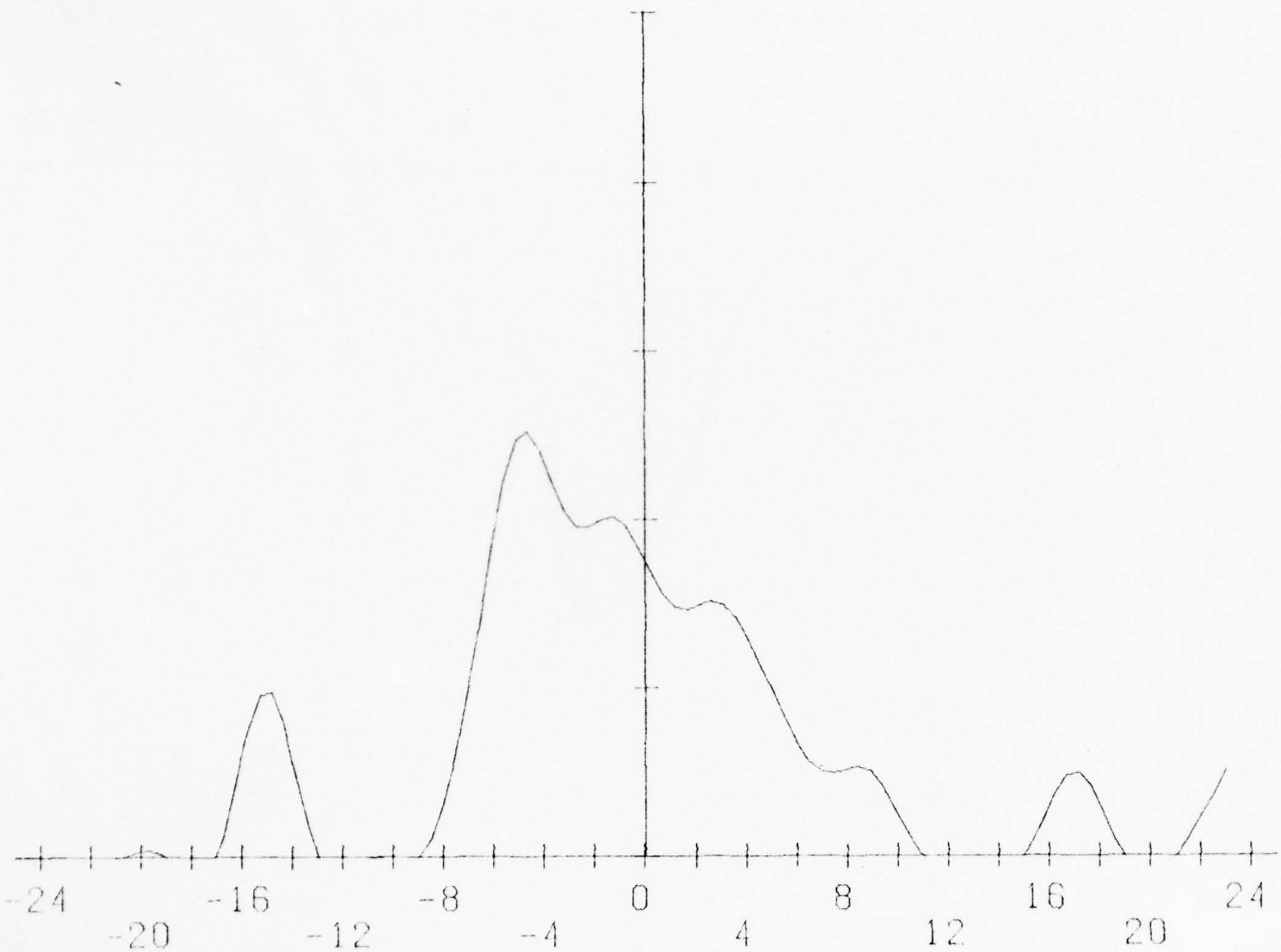

FIGURE C.10 DO41 ERROR DISTRIBUTION FOR LEAD TIME 2

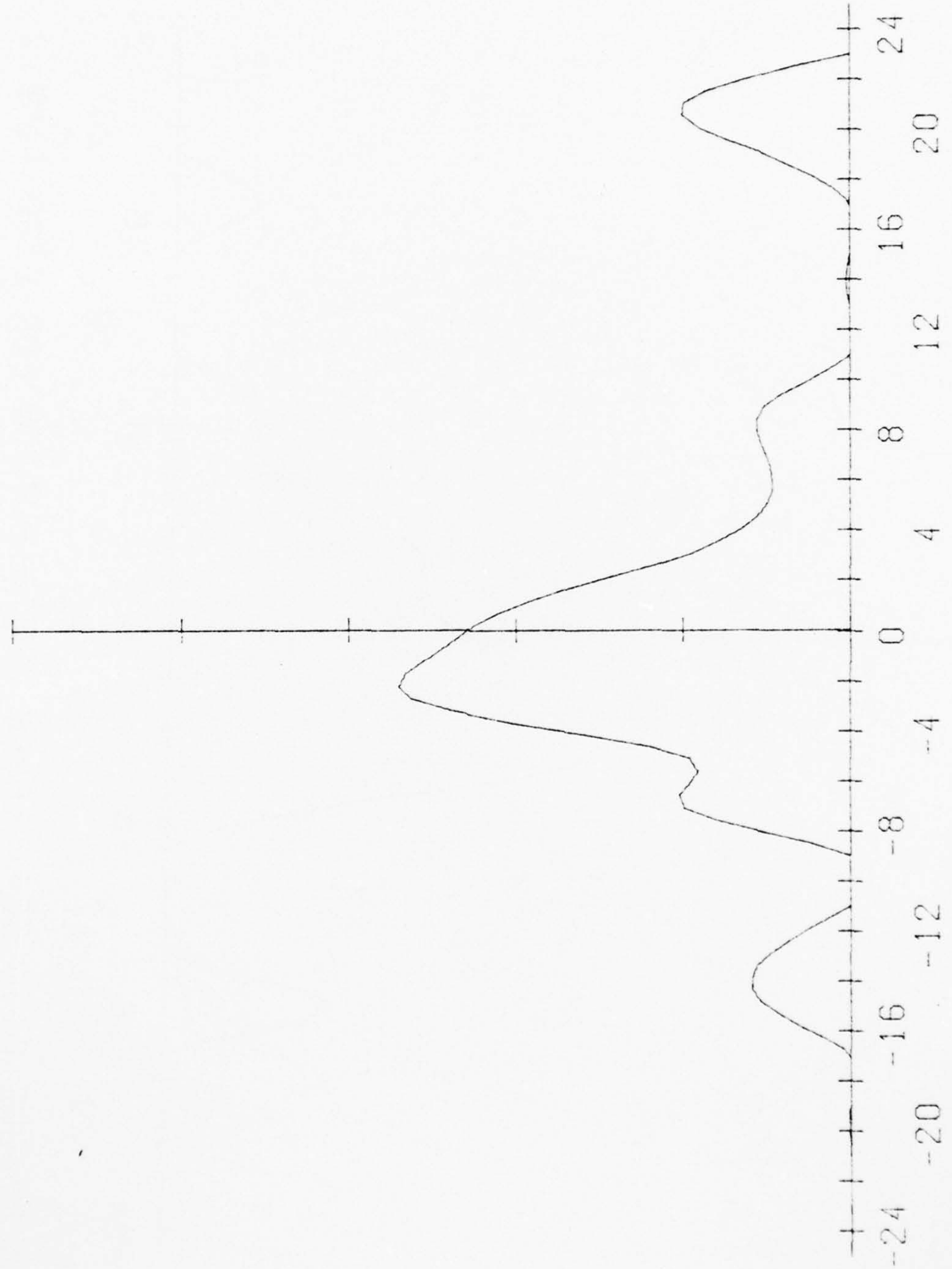

FIGURE C.11 D041 ERROR DISTRIBUTION FOR LEAD TIME 3

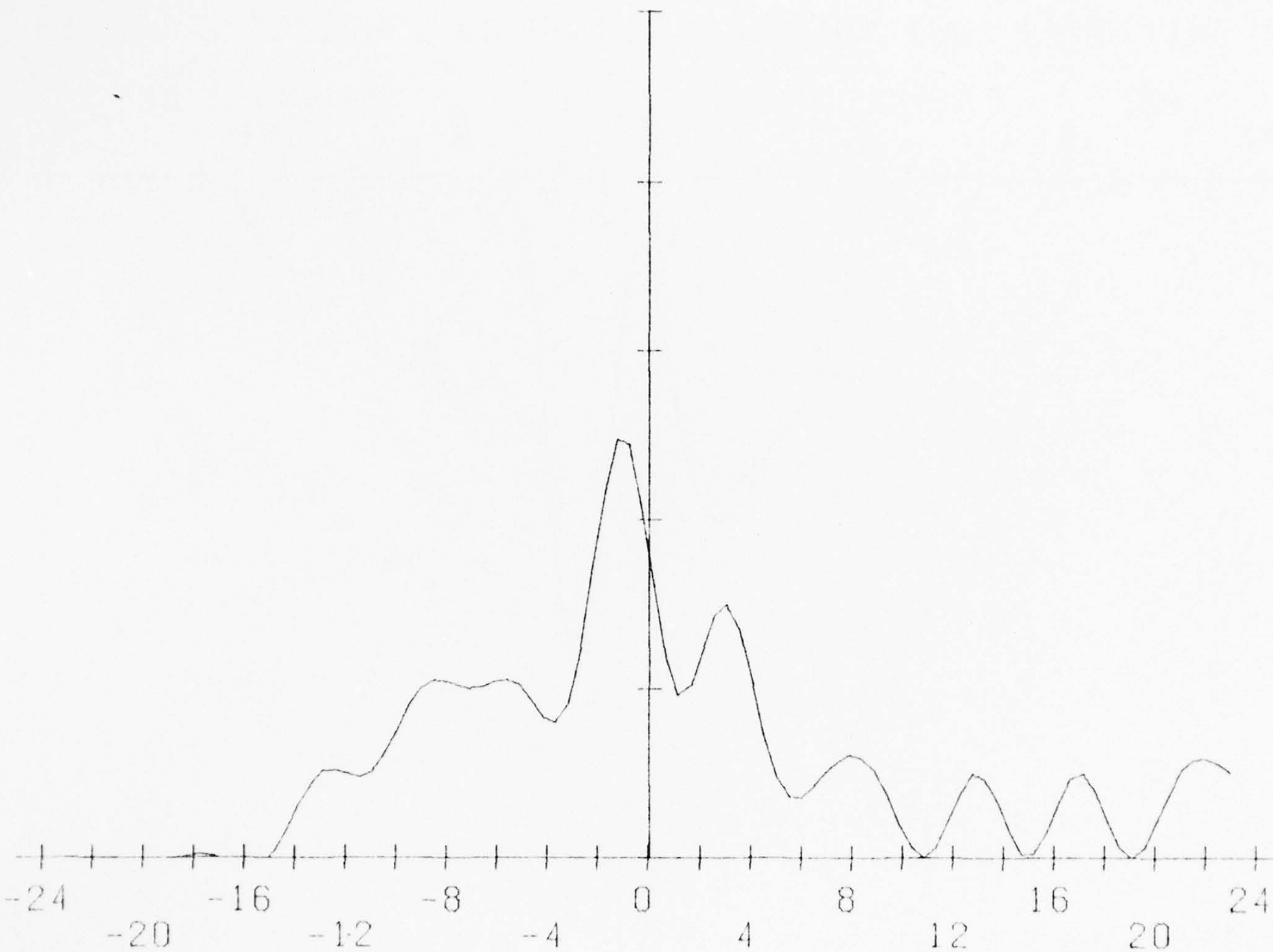

FIGURE C.12 DO41 ERROR DISTRIBUTION FOR LEAD TIME 4

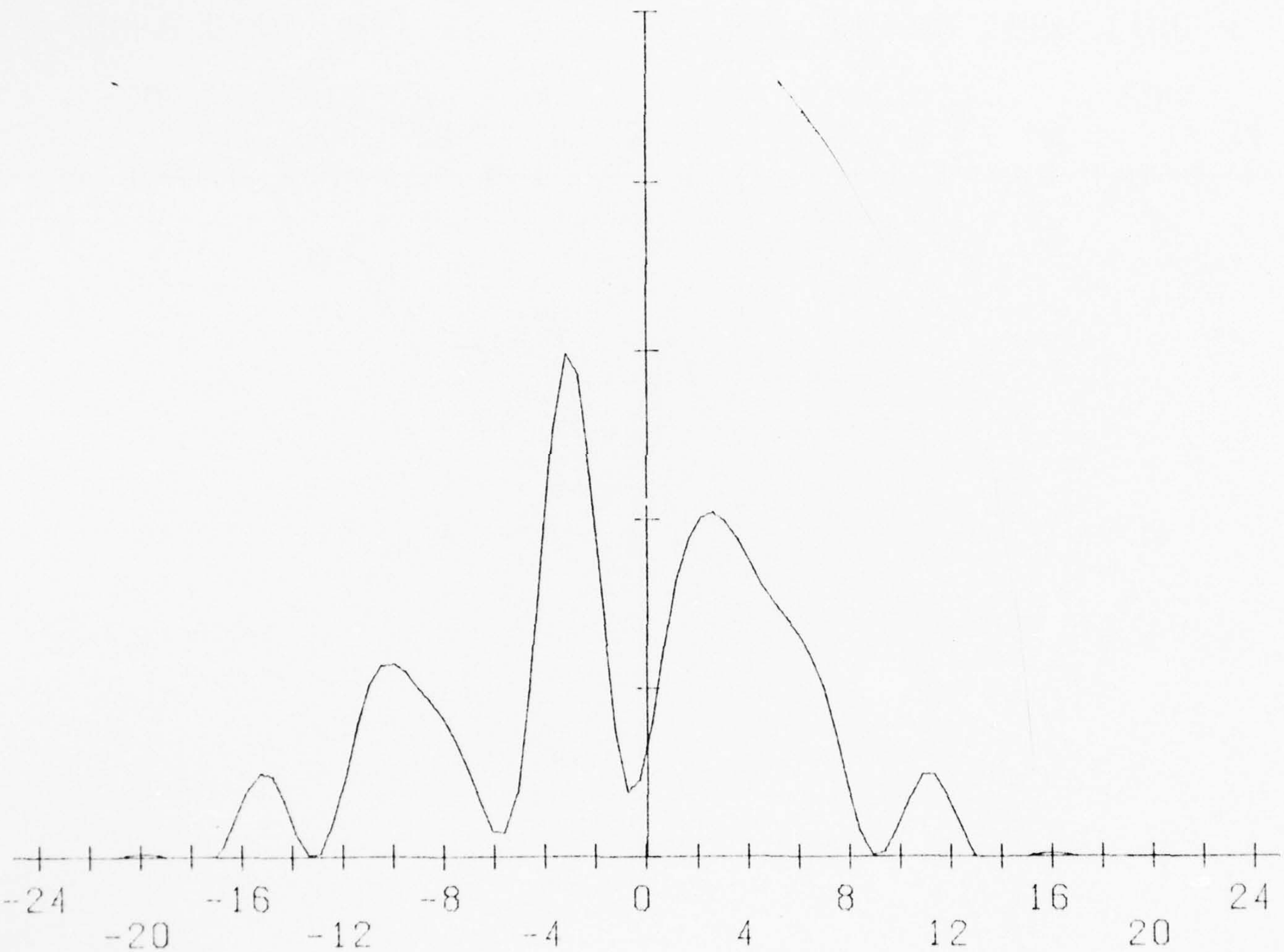

FIGURE C.13 TCAST ERROR DISTRIBUTION FOR LEAD TIME 1

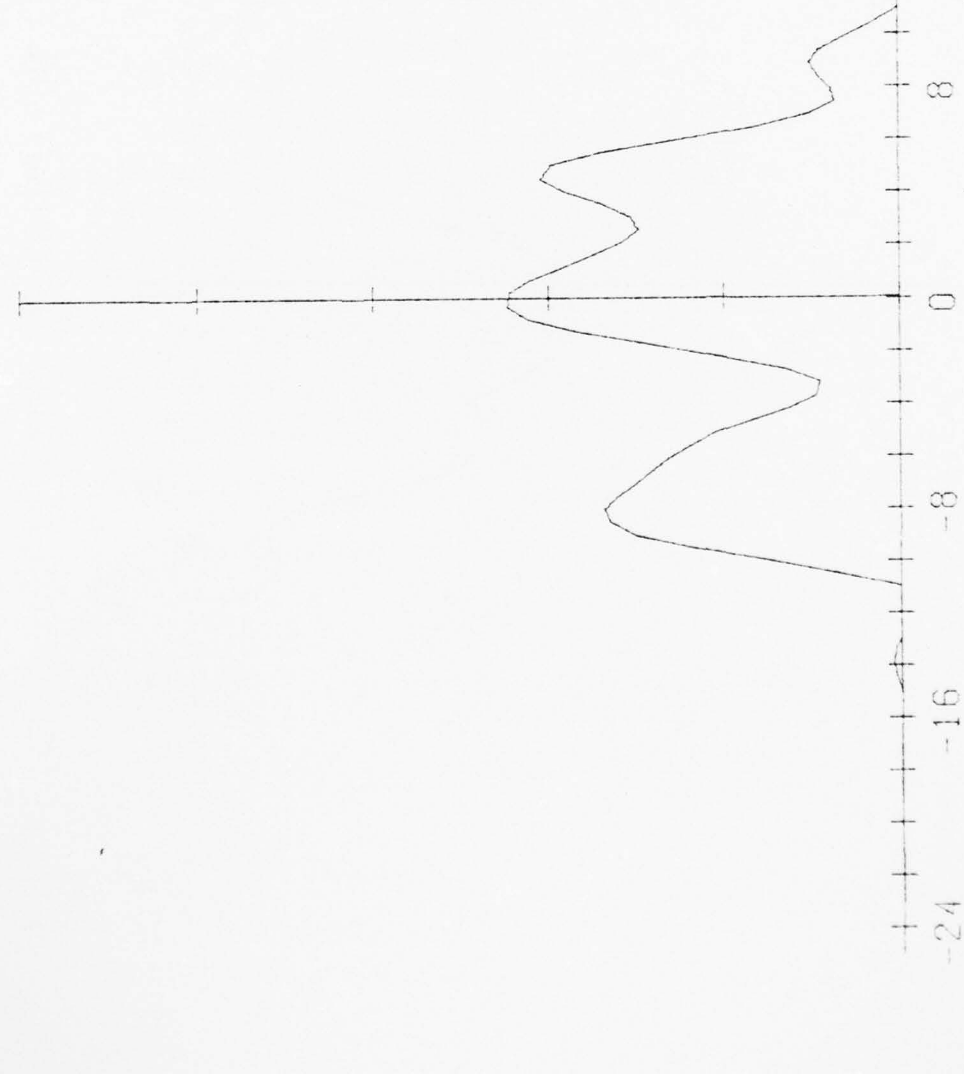

FIGURE C.14 TCAST ERROR DISTRIBUTION FOR LEAD TIME 2

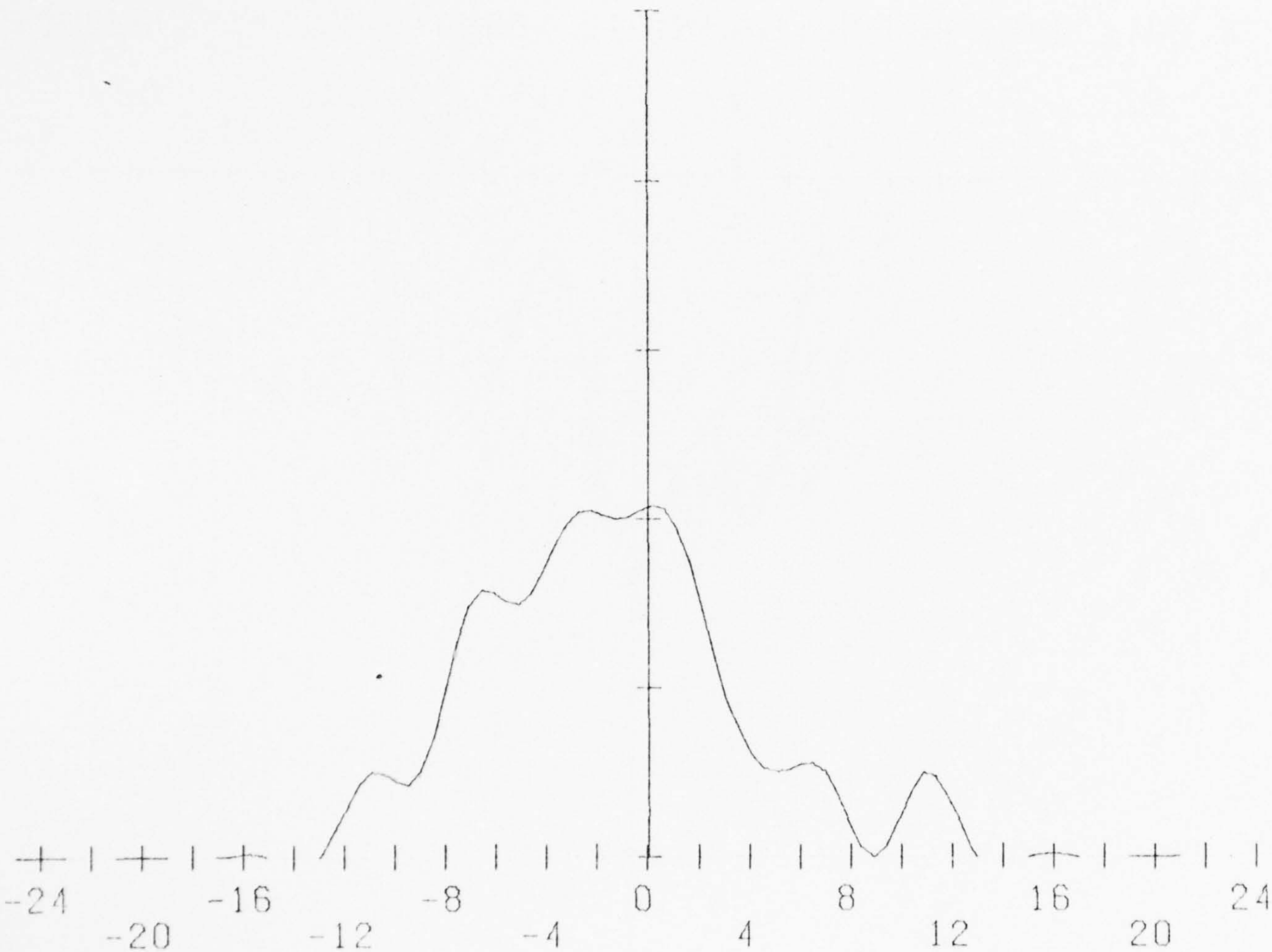

FIGURE C.15 TCAST ERROR DISTRIBUTION FOR LEAD TIME 3

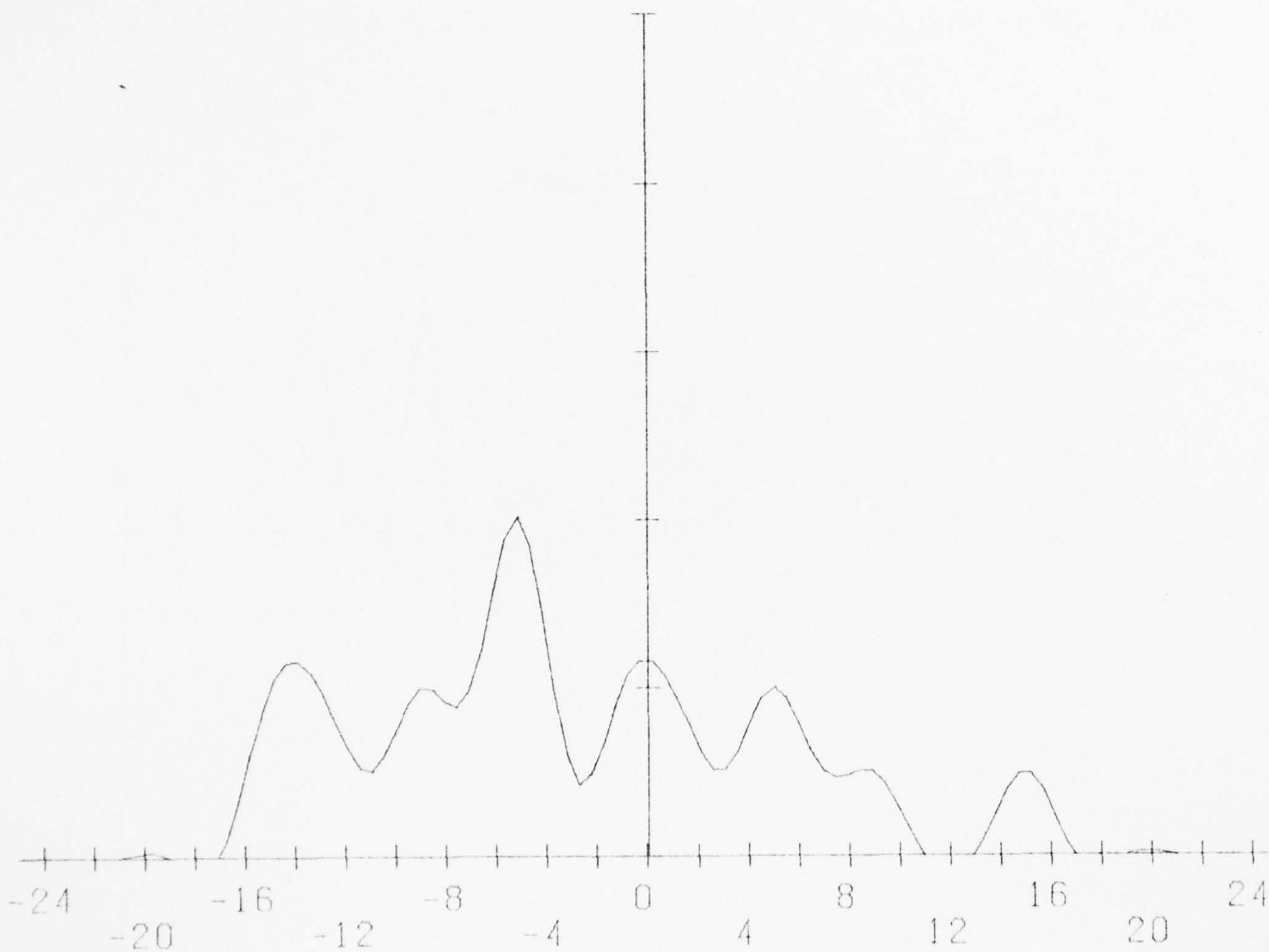

FIGURE C.16 TCAST ERROR DISTRIBUTION FOR LEAD TIME 4

AD-A044 078 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OHIO SCHO--ETC F/G 15/5
A COMPARATIVE ANALYSIS OF THE D041 SINGLE MOVING AVERAGE AND OT--ETC(U)
JUN 77 J S BRANTLEY, D E LOREMAN
UNCLASSIFIED AFIT-LSSR-7-77A NL

2 OF 2
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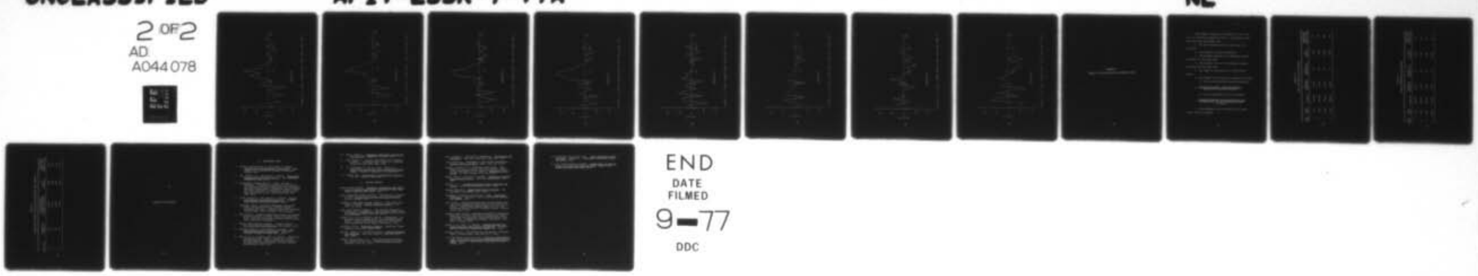

END
DATE
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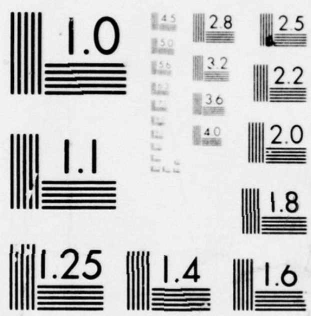
9-77
DDC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

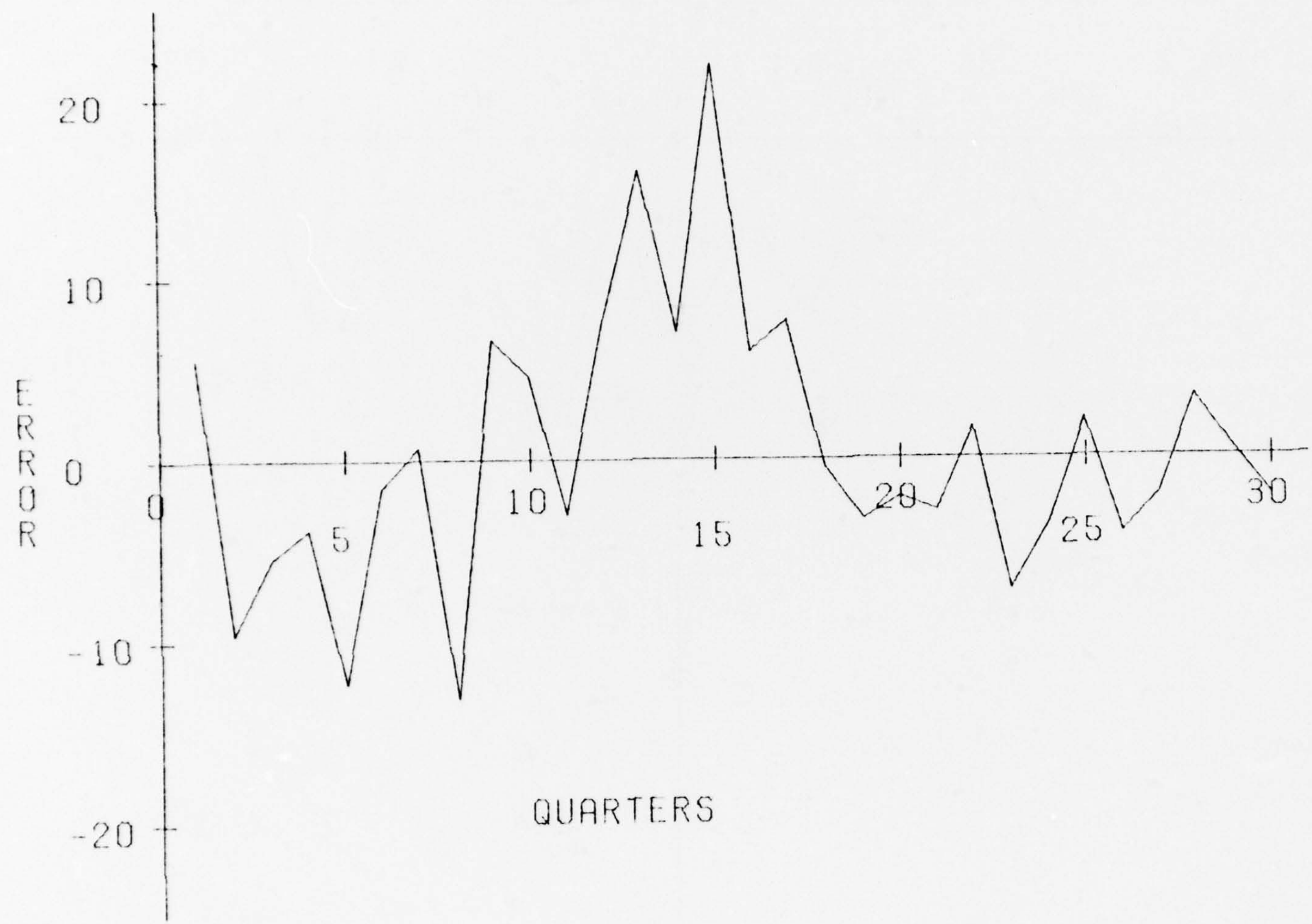


FIGURE C.17 D041 ERROR OVER TIME FOR LEAD TIME 1

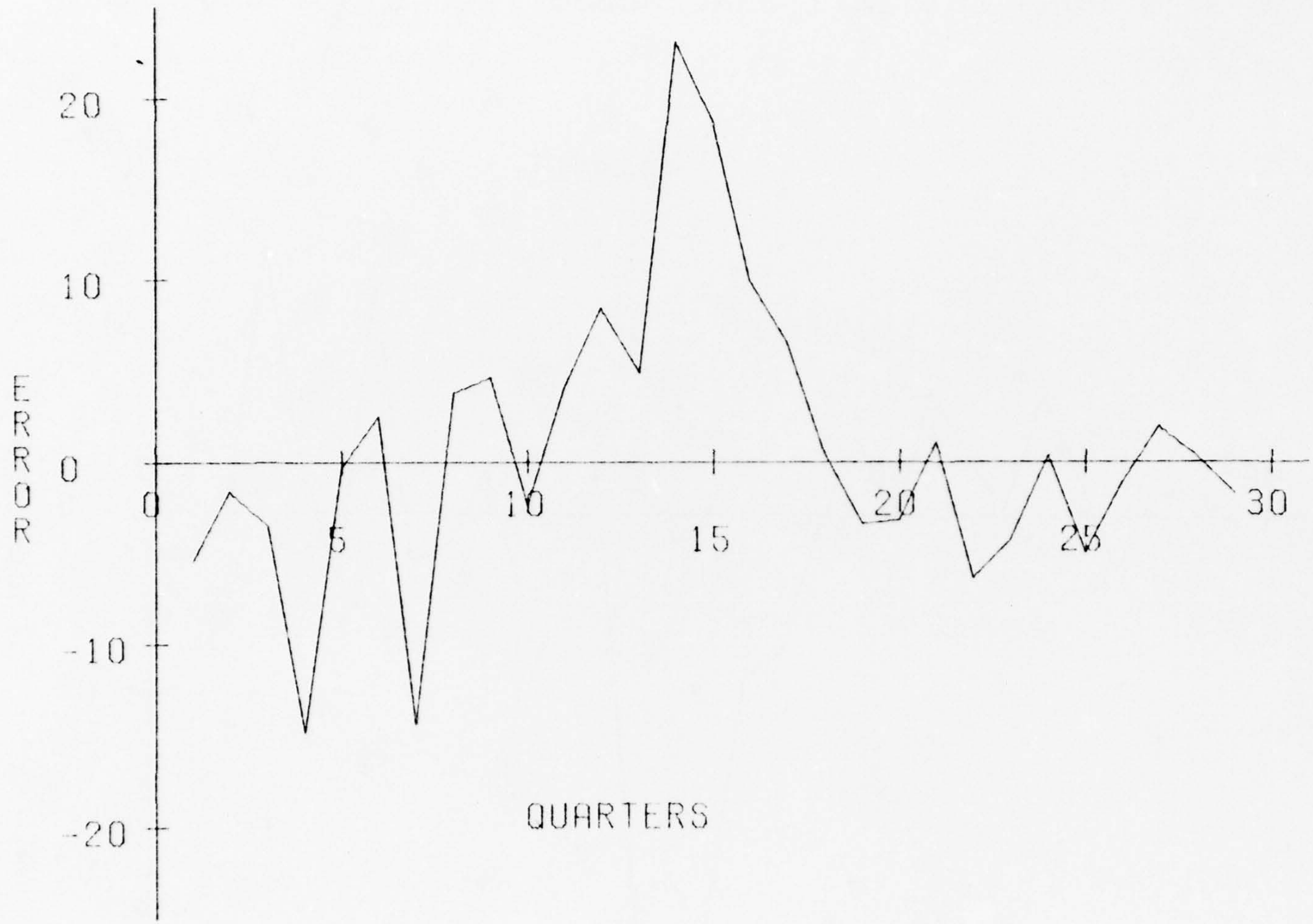


FIGURE C.18 D041 ERROR OVER TIME FOR LEAD TIME 2

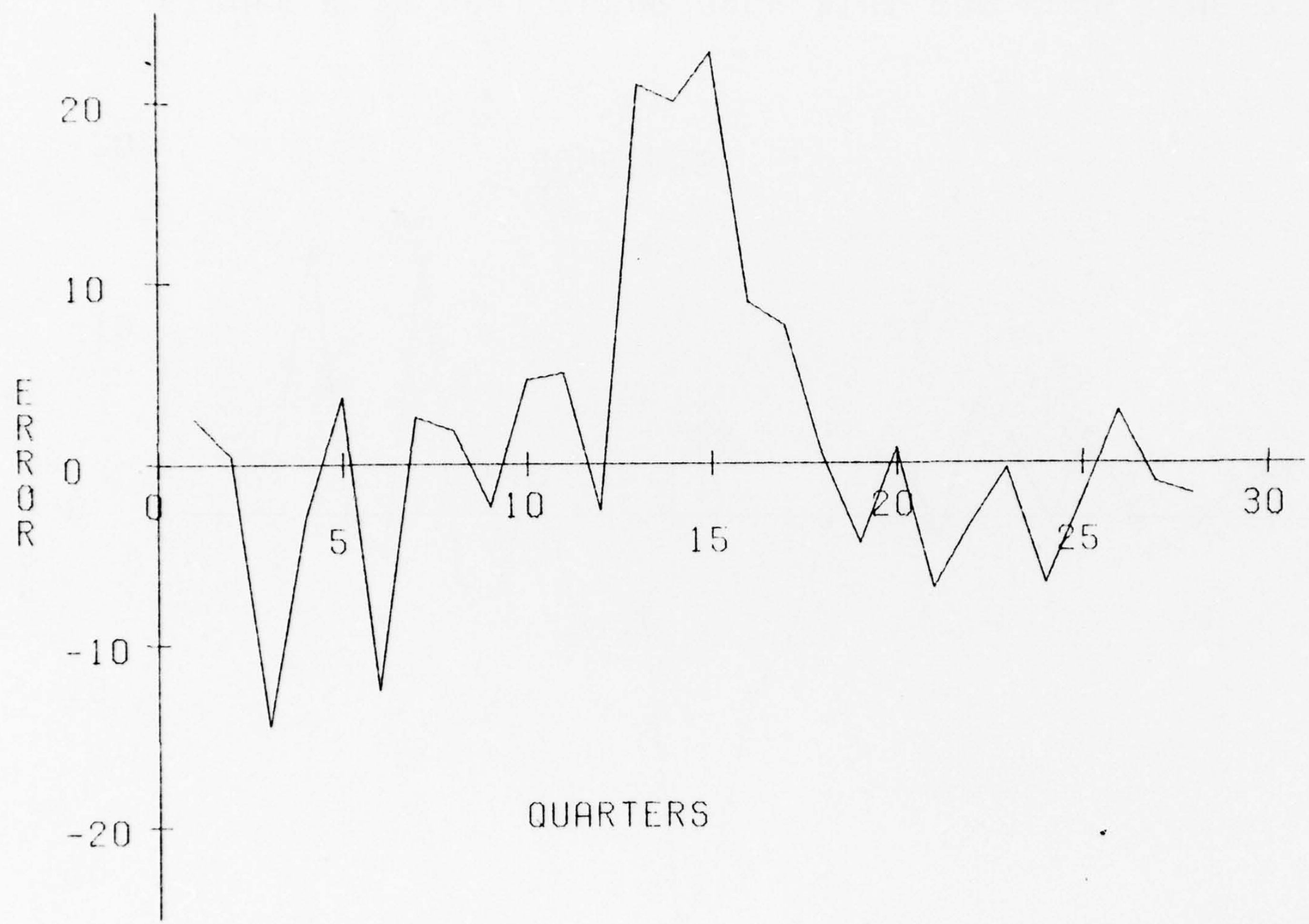


FIGURE C.19 D041 ERROR OVER TIME FOR LEAD TIME 3

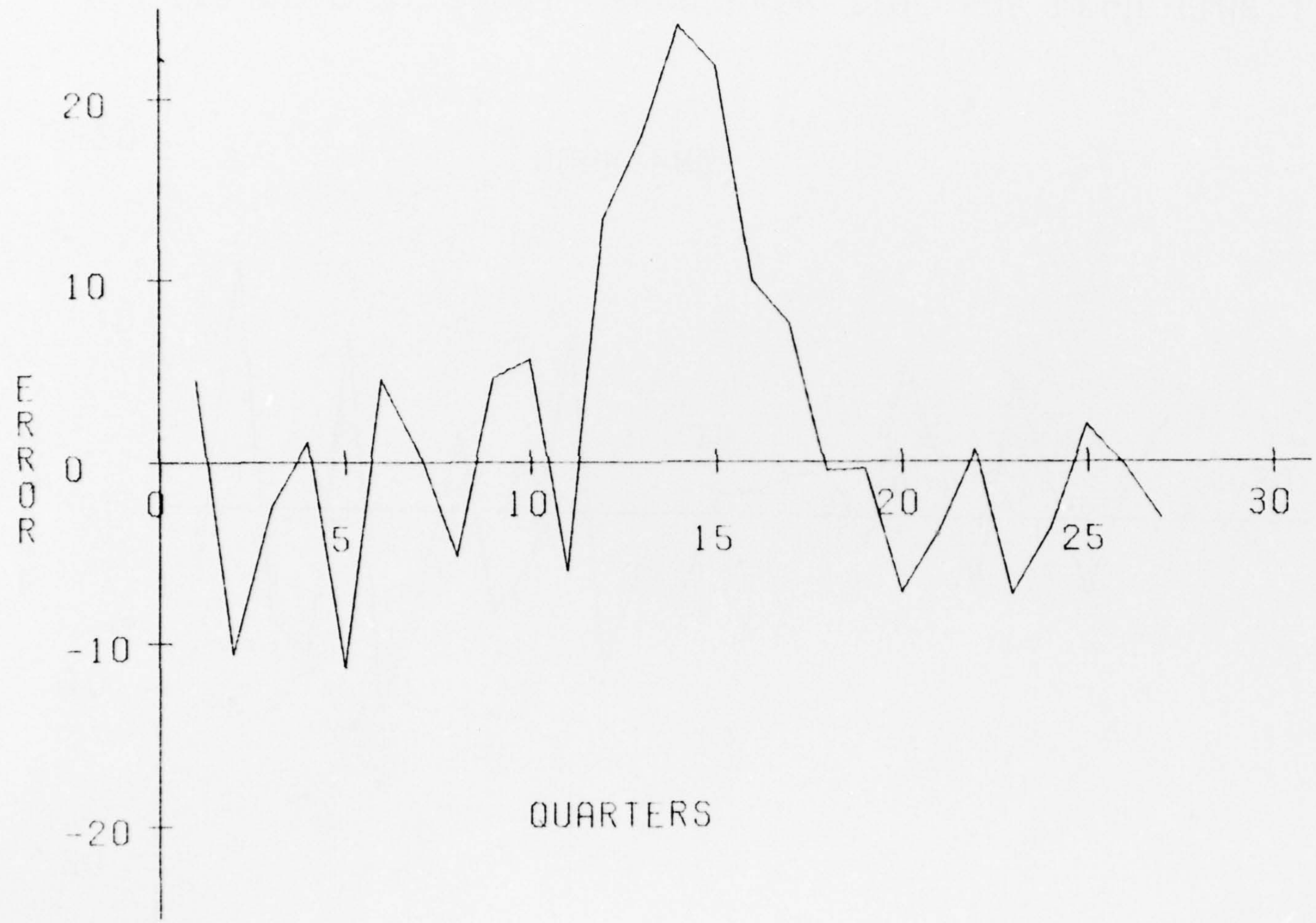


FIGURE C.20 D041 ERROR OVER TIME FOR LEAD TIME 4

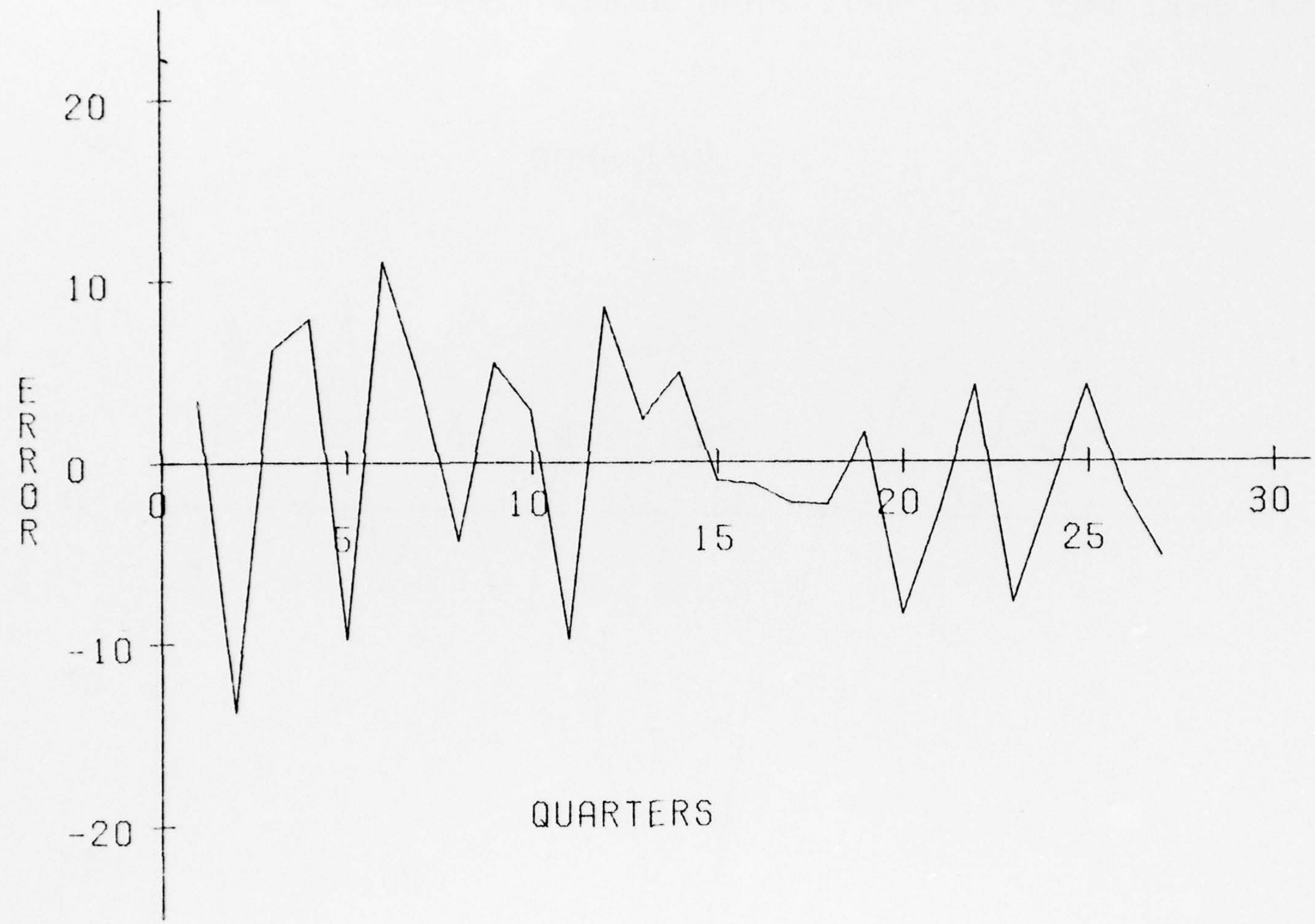


FIGURE C.21 TCAST ERROR OVER TIME FOR LEAD TIME 1

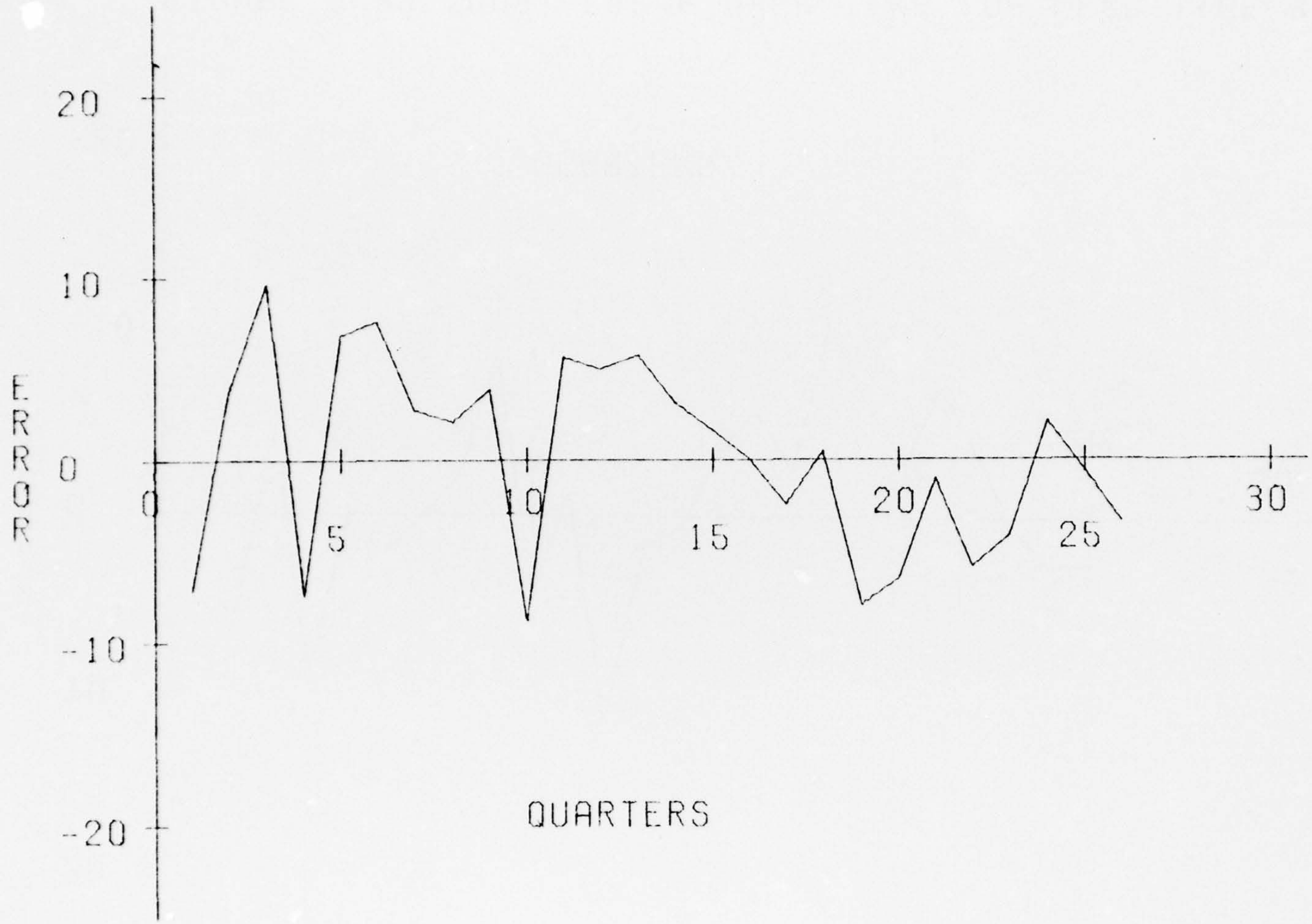


FIGURE C.22 TCAST ERROR OVER TIME FOR LEAD TIME 2

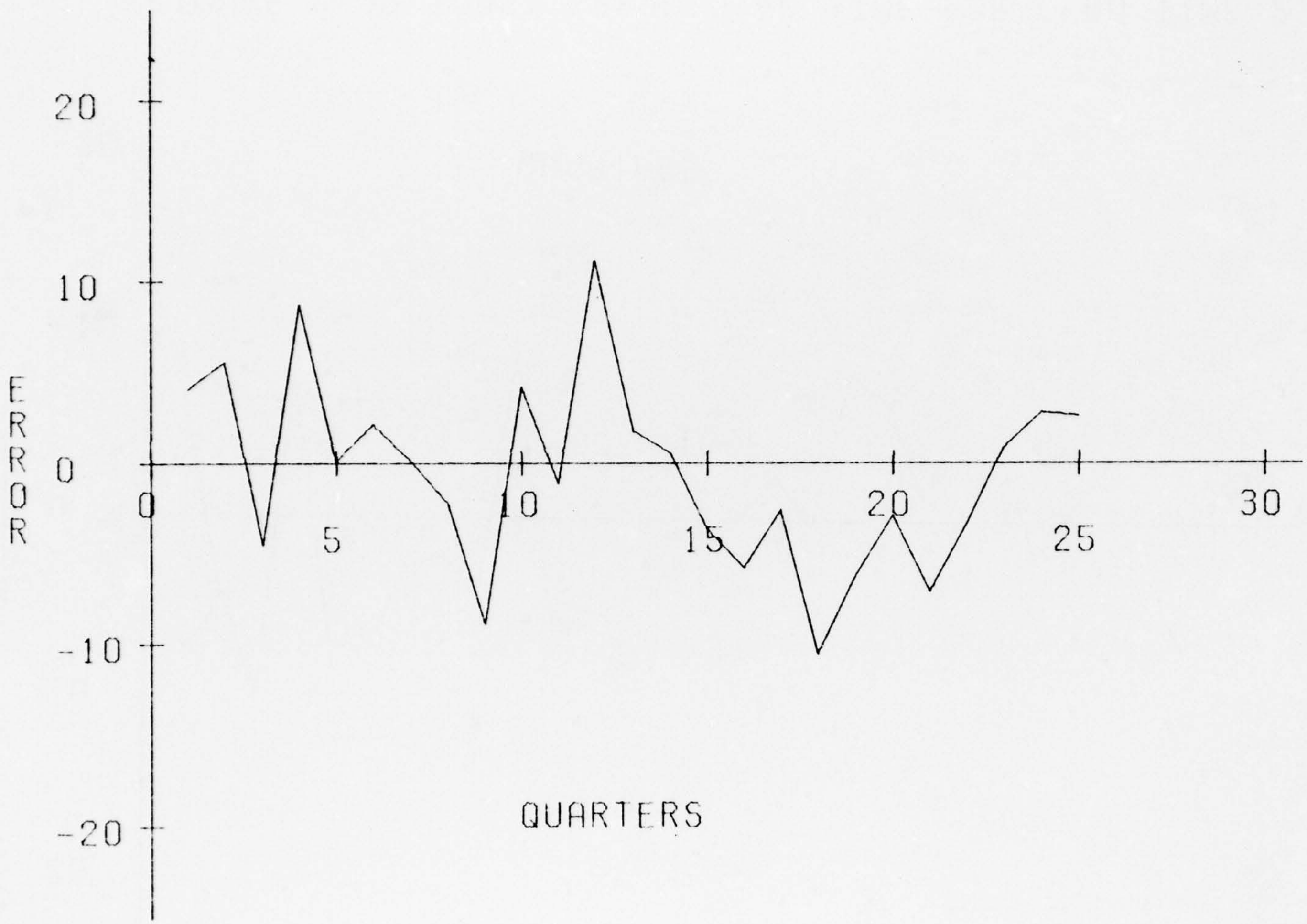


FIGURE C.23 TCAST ERROR OVER TIME FOR LEAD TIME 3

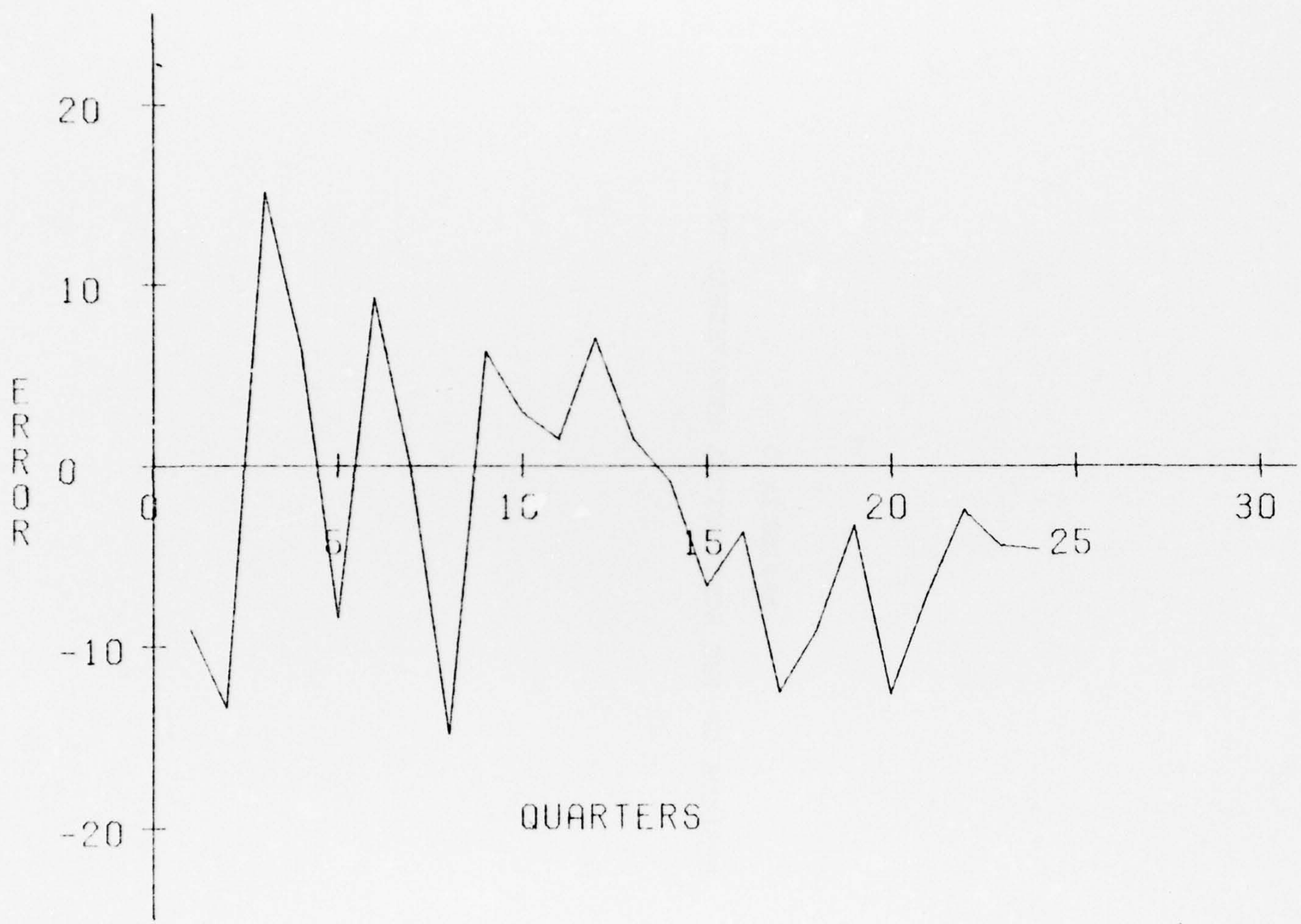


FIGURE C.24 TCAST ERROR OVER TIME FOR LEAD TIME 4

APPENDIX D

RESULTS OF THE STATISTICAL HYPOTHESIS TESTS

This appendix tabulates (see Tables D.1, D.2, and D.3) the following information used in, and resulting from, the statistical hypotheses test:

1. The mean forecast error for each error distribution.

2. The variance of each distribution.

3. The standard deviation for difference between the means for each lead time.

4. The standard error of the difference between the means for each lead time.

5. The number of observations for each distribution.

6. The Student t Test Statistic computed as follows:

a. For the D041 and TCAST error distribution;

$$t = \frac{\text{distribution means - hypothesized mean}}{\text{distribution standard deviation}}$$

b. For the comparison of the two methods;

$$t = \frac{\text{difference between error distribution mean}}{\text{standard error of the difference between the means}}$$

7. The confidence level at which the null hypothesis could be rejected.

TABLE D.1

D041 HYPOTHESIS TEST RESULTS

Lead Time	Mean Error	Variance	Standard Deviation	Number of Observations	Test Statistic	Confidence Level for Rejecting H_0
1	.517	55.897	7.476	30	.379	.32
2	.883	62.536	7.908	29	.601	.44
3	1.650	75.031	8.662	28	1.008	.69
4	2.178	82.248	9.669	27	1.248	.78

TABLE D.2

TCAST HYPOTHESIS TEST RESULTS

Lead Time	Mean Error	Variance	Standard Deviation	Number of Observations	Test Statistic	Confidence Level for Rejecting H_0
1	-.096	38.827	6.231	27	-.416	.32
2	.269	28.174	5.308	26	.258	.20
3	-.516	27.363	5.231	25	.493	.34
4	-2.558	61.376	7.834	24	-1.600	.87

TABLE D.3

FORECASTING METHOD COMPARISON HYPOTHESIS TEST RESULTS

Lead Time	Degree of Freedom	Standard Error of the Difference Between the Means	Test Statistic	Confidence Level for Rejecting H_0
1	55	1.865	.225	.18
2	53	1.871	.328	.25
3	51	2.032	.558	.42
4	49	2.440	-.156	.14

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